NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A HEAT TRANSFER MODEL FOR A
HEATED HELIUM AIRSHIP

by

Ray Maurice Rapert

March 1987

Thesis Advisor: Donald M. Layton

A183786

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b DECLASSIFICATION DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b OFFICE SYMBOL (If applicable) Code 67
7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School	
6c ADDRESS (City, State, and ZIP Code) Monterey, Ca. 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, Ca. 93943-5000
8a NAME OF FUNDING SPONSORING ORGANIZATION	8b OFFICE SYMBOL (If applicable)
9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

A HEAT TRANSFER MODEL OF A HEATED HELIUM AIRSHIP

12 PERSONAL AUTHOR(S) Rapert, Ray M.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year Month Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1987, March	85

16 SUPPLEMENTARY NOTATION

17 COSATI CODES: FIELD	GROUP	SUB-GROUP	18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
			Heat transfer, Airship, Heated Helium Airship, Steam injection

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Basic heat transfer empirical and analytic equations are applied to a double envelope airship concept which uses heated Helium in the inner envelope to augment and/or control gross lift. The convective and conductive terms lead to a linear system of five equations for the concept airship, with the nonlinear radiation terms included by an iteritive solution process.

A FORTRAN program is used to perform the tedious calculations, and graphed results are obtained for the variables of interest. These indicate that a simple use of airship engine exhaust heat will give more than a 30% increase in gross airship lift. Possibly more than 100% increase can be achieved if a "steam injection" heating system, with associated design problems, is used.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Donald M. Layton	22b TELEPHONE (Include Area Code) (408) 646 2997 — 22c OFFICE SYMBOL Code 67Ln

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Approved for public release; distribution is unlimited

A Heat Transfer Model for a Heated Helium Airship

by

Ray Maurice Rapert
Captain, United States Marine Corps
B.S., University of Arkansas, 1976

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1987

Author: Ray Maurice Rapert
Ray Maurice Rapert

Approved by: Donald M. Layton
Donald M. Layton, Thesis Advisor

M. F. Platzer
M. F. Platzer, Chairman, Department of
Aeronautical Engineering

G. E. Schacher
Gordon E. Schacher, Dean of Science
and Engineering

ABSTRACT

Basic heat transfer empirical and analytic equations are applied to a double envelope airship concept which uses heated Helium in the inner envelope to augment and/or control gross lift. The convective and conductive terms lead to a linear system of five equations for the concept airship, with the nonlinear radiation terms included by an iteritive solution process.

A FORTRAN program is used to perform the tedious calculations, and graphed results are obtained for the variables of interest. These indicate that ~~a~~ the simple use of airship engine exhaust heat will give more than a 30% increase in gross airship lift. Possibly more than 100% increase can be achieved if a "steam injection" heating system, with associated design problems, is used. (Theses)

(use single quotes)

TABLE OF CONTENTS

LIST OF FIGURES--6

TABLE OF SYMBOLS AND ABBREVIATIONS-----------------------7

ACKNOWLEDGEMENT---11

I. NATURE OF THE PROBLEM--------------------------------12

A. CONTROL OF LIFT--------------------------------------12

B. HISTORY--12

C. RESEARCH FINDINGS------------------------------------13

II. THE PHYSICAL MODEL----------------------------------15

A. A PRACTICAL MODEL------------------------------------15

B. HEATING CONSIDERATIONS-------------------------------17

C. ALTERNATIVES AND IMPROVEMENTS------------------------18

III. THE MATHEMATICAL MODEL-----------------------------22

A. THE HEAT TRANSFER PROBLEM IN GENERAL-----------------22

B. CONDUCTION AND CONVECTION MODELLING------------------23

C. RADIATION HEAT TRANSFER------------------------------28

D. THE RESULTING SET OF LINEARIZED EQUATIONS------------31

E. THE COMPUTER PROGRAM---------------------------------33

IV. RESULTS---38

A. PROGRAM OUTPUT---------------------------------------38

B. ESTIMATES OF ACCURACY--------------------------------40

V. CONCLUSIONS--49

APPENDIX A: PROGRAM HOTSHIP-----------------------------51

APPENDIX B: PROGRAM SAMPLE OUTPUTS----------------------57

APPENDIX C: COMPUTATION OF AVAILABLE ENGINE WASTE HEAT---81

APPENDIX D: CALCULATIONS OF VALUES FOR STEAM INJECTION---82
LIST OF REFERENCES--83
INITIAL DISTRIBUTION LIST---------------------------------84

LIST OF FIGURES

1. Airship Concept Geometry Overview ----------------- 17

2. Inner Envelope Suspension ------------------------ 18

3. Idealized Envelope Shapes ------------------------ 23

4. Temperature Profile ------------------------------ 27

5. Equivalent Fuel Flow vs Delta T ------------------ 39

6. Equivalent Fuel Flow vs Delta T (Large Scale) ----- 40

7. Q vs Delta T ------------------------------------- 41

8. Change in Lift vs Delta T ------------------------ 43

9. Change in Lift vs Q ------------------------------ 44

10. Q vs Velocity ----------------------------------- 45

TABLE OF SYMBOLS AND ABBREVIATIONS

PROGRAM NAME	TEXT SYMBOL	DEFINITION
A	A	Generic area or matrix value
AHTR	A_{htr}	Heater effective radiant area
AIN	$A_{in}=A_i$	Inner envelope effective area
AOUT	$A_{out}=A_o$	Outer envelope area
B	B	Generic matrix value
C	C	Generic matrix value
	Cp_{air}	Specific heat of air
	d	Envelope spacing
DELT	Delta T	Temperature difference
DLH2O		Change in lift due to steam volume
DLIFT		Change in lift (lbf) from temperature increase
DLTOT		Total change in lift
DMDT	m_f	Equivalent fuel burn rate
DQDTN		"New" value of heat flux computed in present iteration
DQDTR0	q_{r0-2}	Radiative heat flux from heater surface to the inner envelope
DQDTR3	q_{r3-4}	Radiative heat flux between the envelopes
DVH2O		Increase in volume due to steam
E	E	Generic matrix value
EHTR	ε_{htr}	Emissivity of heater surface
EIN	ε_{in}	Emissivity of inner envelope
EOUT	ε_{out}	Emissivity of outer envelope

GR	Gr	Grashof Number
GRD	Gr_d	Grashof Number based on envelope radius difference
GRFL	Gr_{fl}	Grashof Number based on fluid temperature
	h	Convective heat transfer coefficient
H1	h_1	Convective heat transfer coefficient for the inner volume
H1AIR	h_{air}	Convective heat transfer coefficient based on properties of air
H4	h_4	Convective heat transfer coefficient for the outer surface
KAIR	k_{air}	Thermal conductivity for air
KEQV	k_{eqv}	Thermal conductivity-equivalent computed value
KFL	k_{fl}	Thermal conductivity based on fluid temperature
KHE	k_{he}	Thermal conductivity for Helium
KIN	$k_{in}=k_i$	Thermal conductivity for the inner envelope
KINF	k_{inf}	Thermal conductivity (of air) based on outside air temperature
KMEAN	k_{mean}	Thermal conductivity (of air) based on volume mean temperature between the envelopes
KOUT	$k_{out}=k_o$	Thermal conductivity for the outer envelope
L	L	Airship length
MUAIR	μ_{air}	Viscosity of air
MUFL	μ_{fl}	Viscosity based on fluid temperature
MUHE	μ_{He}	Viscosity of Helium
MUI	μ_{inf}	Viscosity based on outside temperature

MUMN		Viscosity based on volume mean air temperature
	Nu	Nusselt Number
	Nu_{air}	Nusselt Number for air
	Nu_{He}	Nusselt Number for Helium
PDL		Percent change in lift due to temperature increase only
PDLTOT		Total percent change in lift
	Pr	Prandtl Number
PRFL	Pr_{fl}	Prandtl Number based on fluid temperature
PRI	Pr_{inf}	Prandtl Number based on outside air temperature
PRMN	Pr_{mn}	Prandtl Number based on mean fluid temperature
Q	q	Heat flux
RE	Re	Reynolds number
REL	Re_L	Reynolds number based on airship length
RHOAIR	ρ_{air}	Density of air
RHOFL	ρ_{fl}	Density based on fluid temperature
RHOHE	ρ_{He}	Density of Helium
RHOI	ρ_{inf}	Density based on outside air temperature
RHOMN	ρ_{mn}	Density based on mean fluid temperature
RIN	R_{in}	Inner envelope effective radius
RINIT		Iteration initial trial radius
RMAX	R_{max}	Maximum radius
RMEAN	Rm	Average of inner and outer envelope radii

ROUT	R_{out}	Outer envelope radius
RTRY		Present iteration trial radius
	shp	Shaft horsepower
SPV	v	Specific volume (of water vapor)
SUM		Value used in system solution
T	T	Generic temperature
TO	T_0	Inner volume mean fluid temperature
T2	T_2	Temperature on inner surface of inner envelope
T3	T_3	Temperature on outer surface of inner envelope
T4	T_4	Temperature on inner surface of outer envelope
T5	T_5	Temperature on outer surface of outer envelope
TFL	T_{fl}	Fluid temperature
THE	T_{He}	Helium temperature
THIN	t_i	Thickness of inner envelope
THOUT	t_o	Thickness of outer envelope
THTR	T_{htr}	Heater surface temperature
TI	T_{inf}	Temperature of outside air
TMEAN	T_m	Volume mean temperature of the air between the envelopes
UI	U_{inf}	Velocity of the airship
VH2OH		Volume of the water vapor with the Helium heated
VH2OI		Volume of water vapor with the Helium unheated
VIN	V_{in}	Inner envelope volume
VTOT	V_{out}	Outer envelope, or total volume

ACKNOWLEDGEMENT

A special thanks is due to my thesis advisor, Professor Donald Layton, whose consistent enthusiasm and encouragement spurred a continuous effort in research and computation for this paper. His broad knowledge and experience in airships provided that basic guidance necessary to stay on the correct research path toward a reasonable concept.

My thanks also to Professor James Miller for guidance and confirmation of work in the heat transfer field.

Background research was aided by several individuals who were willing to take an extra effort to provide useful information or share personal knowledge and experience. These are Mr. John Eney of the Naval Air Development Center, Mr. Mark West of Aerostar, Mr. I. P. Alexander of Wren Skyships, and Mr. Marc de Piolenc for the ABAC Library.

I. NATURE OF THE PROBLEM

A. CONTROL OF LIFT

In a fixed or rotary wing aircraft, the control of lift is normally a simple problem of changing engine power and/or angle of attack on the wing or rotor, and desired lift is quickly attained up to the aircraft's capability limits. Lighter than air ships, however, have a more inherent problem in increasing or decreasing lift. Typically, changes are produced by adding or valving lifting gas, ballasting by some heavy and readily obtained material such as sand or water, or employing engine exhaust based water recovery systems to compensate for fuel burnoff. Disadvantages of these are well known: availability and cost of lifting gas; ballasting material is not always available or easily transferred, and is a one way operation once airborne; and water recovery systems are bulky and heavy.

Control of the lifting gas temperature could provide a more flexible and complete means of lift control. In addition, a significant increase in lifting gas temperature will ideally provide a proportionate increase in gross lift.

B. HISTORY

Using heated lifting gas to control or augment the gross lift of an airship is an old idea, and an obvious extension

of early hot air ballooning. Burgess, in his book "Airship Design" , lists this idea in his Airship Fallacies chapter due to his estimation on the rate of heat loss. He does, however, offer "...gas cell construction in which convective losses were greatly reduced might possibly result in a practical solution of the problem" (reference 1, pp. 288-289). Present day fabrics, films and laminates offer much more flexibility in such construction than the rubberized cotton in use in the early 1900's (references 1 and 2).

C. RESEARCH FINDINGS

A library and information search was conducted to determine whether research results were available for such a heat transfer problem. The following results were obtained:

- Mention in NASA CR137692 (reference 3) that Airfloat Transport, Ltd., had looked at heated Helium at takeoff to eliminate water recovery apparatus. No further information was obtained.

- Concepts on using engine heat to heat lifting gas, but no technical evaluation by Davenport (reference 4).

- A letter from Mr. I. P. Alexander of Wren Skyships, Ltd., stated that Wren Skyships had looked at ballonet heating on the RS-1. Additional mention was made of electrical heating tested on the LZ-130 Graf Zeppelin II. Neither of these concepts proved feasible, but these involved a small modification, and not a basic design concept. No technical data was received.

- In a telephone conversation with Mr. Mark West of Aerostar, he stated that Aerostar had worked with students at Rensselaer Polytechnic Institute on a steam lift blimp design. No technical results were obtainable.

- Extensive hot air and high altitude balloon heat transfer modelling is available. Applicable data from Stefan (reference 5) was modified for use in this model.

Also, applicable gas and film radiative properties were investigated in reference 6.

The conclusion based on this available information is that only limited applications of lifting gas heating have been seriously explored. If a design dedicated to the use of heat to control and augment the lift of a Helium airship has been completed, no comprehensive mathematical modelling for such a design is available.

II. THE PHYSICAL MODEL

A. A PRACTICAL MODEL

A comprehensive design concept for an airship is certainly beyond the scope of this paper. It is, however, desirable to have a reasonable physical concept on which to base the mathematical modelling and derivations. That concept, and some promising alternatives, are briefly explored, and the basis for the mathematical model is set forth.

As encountered in any design, conflicting requirements must be considered, and the final choice of the model is an optimized compromise. Reduction of convective heat transfer, and maximum resistance to heat loss requires a multiplicity of panels within a volume, and insulative material coated onto panels. It is quickly realized, however, that such an airship will not be "lighter than air", and a minimum of envelope yardage and insulation must be pursued.

In the absence of design specifications and "tradeoff" parameters, and in order to generate a simple but effective hypothetical physical model, it is assumed that the weight penalty of insulation material in addition to the inherent insulation properties of the envelope fabrics is prohibitive. Likewise, the use of additional fabric panels,

other than a basic double envelope design, is assumed prohibitive. The resulting concept is basically a conventionally shaped airship (see Figures 1 and 2) with the outer envelope enclosing lifting gas and ballonet volumes, providing basic protection from the external environment, aerodynamic shape, and pressure containment to hold that shape.

An inner envelope contains the lifting gas, and must be expandable to accommodate both heating and altitude variations required for the airship. This envelope, then, must also carry the weight of the airship and loads. The weight suspension system also needs to constrain the shape of this inner envelope in such a way that the gap between inner and outer envelopes is reasonably uniform in order to minimize heat loss. The concept depicted in Figure 2 is of an adjustable/variable catenary cable system suspending the airship loads from the top of the inner envelope. The lengths of the cables are varied through a winch and pulley system to hold a desired pear shape, or natural buoyancy form, within the outer envelope.

The air space between the envelopes is used as the ballonet in a standard fashion, and could, of course, be subdivided as required for safety and airship control. This volume also proves to be the most effective heat loss barrier as might have been expected.

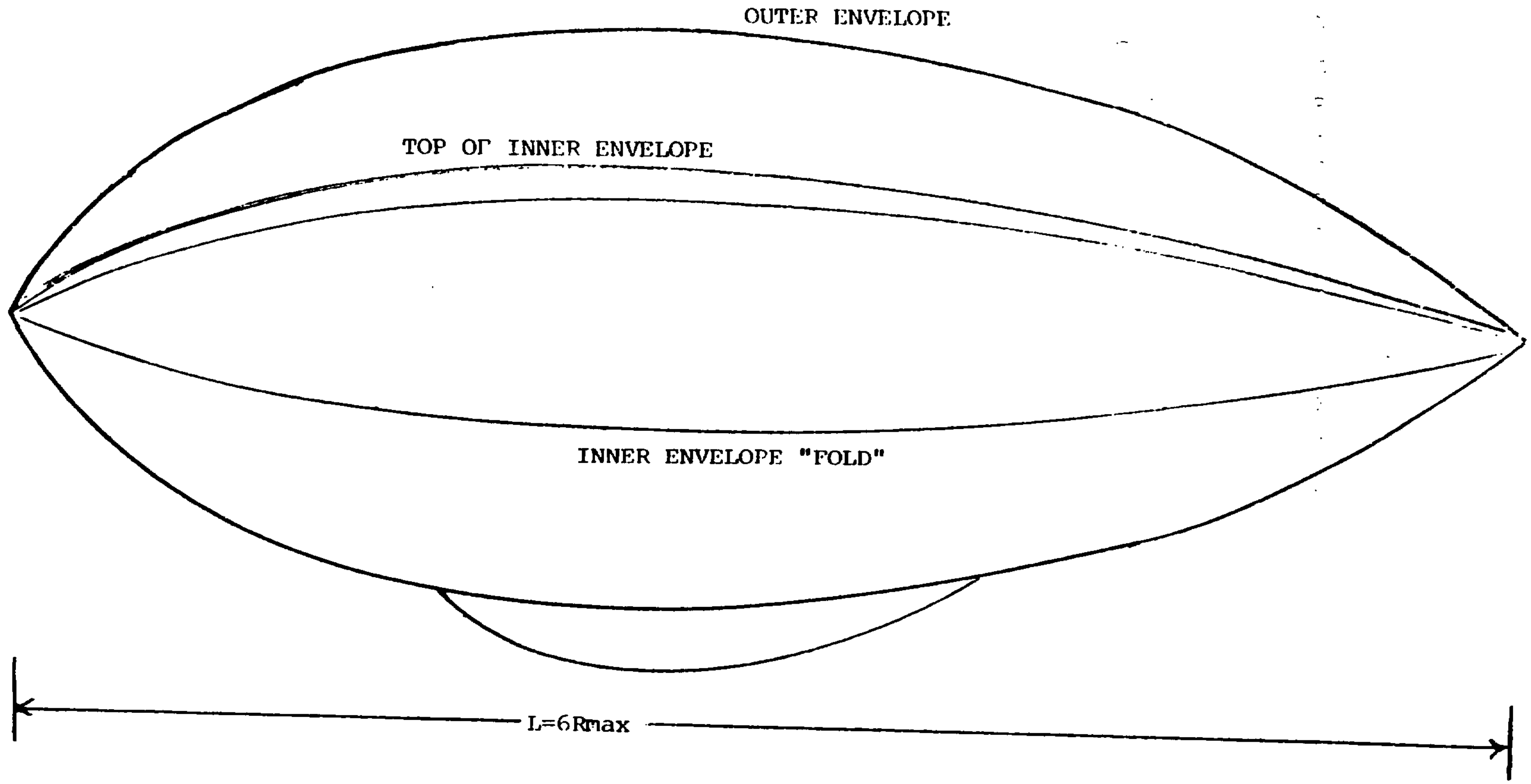

Figure 1: Airship Concept Geometry Overview

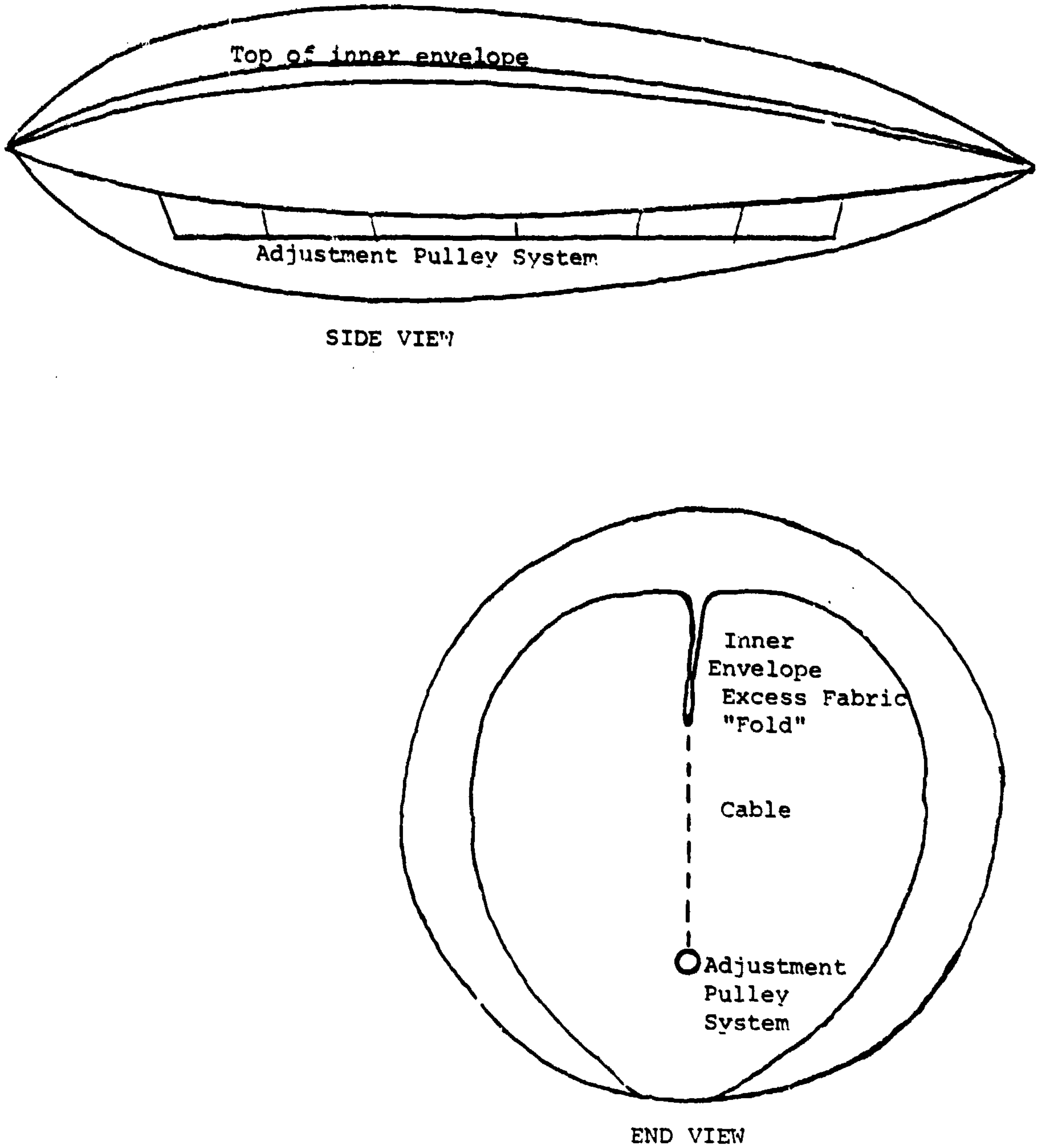

Figure 2: Inner Envelope Suspension

In order to get a solid "feel" of the results from the heat loss rate calculations, specific external dimensions and gross lift capability were chosen to coincide closely with the probable sizes of near future NAVY or Coast Guard airships. These are:

- gross lift of 130,000 lbf (2×10^6 ft^3 of He)
- length of 398.9 ft
- maximum diameter 133 ft
- slenderness ratio ($L/2R_{max}$) = 3
- total volume = 4×10^6 ft^3

Note that the outer envelope volume is twice the initial inner envelope volume.

B. HEATING CONSIDERATIONS

A practical, high capacity, efficient and lightweight system to provide heat into the inner envelope volume is critical to this concept. Low heat intensive systems such as heat pumps are assumed to be prohibitively heavy in the capacity ranges required. A simple air fed and vented petroleum based liquid burning heater may be a reasonable solution to these requirements.

Davenport, in reference 4, proposes the use of engine exhaust to heat this volume. Appendix C shows a simple derivation of the amount of waste heat produced in engines such as may be used for propulsion of an airship this size. The problem of efficiently transferring this heat to the inner volume still remains. Forced air ducting and/or exhaust ducting may be the best, if least efficient means.

Since the heat exchange system required between hot ducting or heater surfaces and the inner Helium volume might be extensive and heavy, the injection of steam produced from a low pressure boiler or engine manifolds directly into the Helium is considered as a possible alternative. Section III,B,4 of this paper contains some comments on the difficulties of estimating the inner envelope heat transfer characteristics with saturated Helium and the condensation of water vapor on the inner envelope. Some foreseen detrimental factors in the use of such a system are the weight of the condensate on the inside of the inner envelope, corrosion or environmental effects on the inner envelope, weight of water required, and the energy to evaporate that water. A rough calculation of these values is completed in Appendix D. Benefits of the use of such a system are seen in section IV.

C. ALTERNATIVES AND IMPROVEMENTS

Using the inner volume as ballonet, with the lifting gas volume between the envelopes, has two significant advantages over the chosen model. First, the more elaborate suspension system for the inner envelope is not required. Second, an open burner or direct injection and mixing of heated air into the inner volume makes a heat exchange ducting network unnecessary. A third benefit, heating the heavier air, and thus reducing the density proportionately, is seen to be a fallacy due to the fact that a fixed Helium mass is

retained, while the air mass is discharged to hold a constant total volume. This alternative concept has the disadvantage of a reduced heated volume as temperature or altitude are increased, while in the chosen concept, the directly heated volume will increase with these parameters.

An easy improvement to the modelled concept would be the use of lightweight panels such as a mylar film to break up the convective patterns. No estimate of the effectiveness of these panels is attempted in the present model.

Further research might result in fabrication techniques for envelopes with dramatically increased heat loss resistance. One approach is to trap relatively thick air layers between mylar films of the fabric composites, which could result in a factor of 10 increase in this value.

III. THE MATHEMATICAL MODEL

A. THE HEAT TRANSFER PROBLEM IN GENERAL

Analytical solutions to the convective heat transfer problem are limited to laminar flow over specified geometries (reference 7). Empirical data curve fits must be used to apply known heat transfer characteristics to this airship heat loss problem. Since the available empirical equations apply to specific geometries, the airship shape is initially idealized as in Figure 3, with a hemispherical nose, cylindrical body, and conical tail.

With a fixed slenderness ratio for the external shape, $L/2R_{max} = 3$, the relationship between maximum diameter, envelope surface area and volume in this idealized model is fixed from basic solid geometry as:

$$R_{max} = (3V/13\pi)^{1/3} = (A/\pi(8+\sqrt{5}))^{1/2}$$

$$A = (8+\sqrt{5})(3V/13\pi)^{2/3}$$

The inner envelope is idealized as a shape concentric to the outer envelope (Figure 3), with the total length the same as the outer envelope, but with the diameter varied as required to contain the lifting gas volume with changes in temperature (and altitude). With a constant proportion for the hemispherical nose and conical tail, the required length is derived for the cylindrical body, and again from solid geometry:

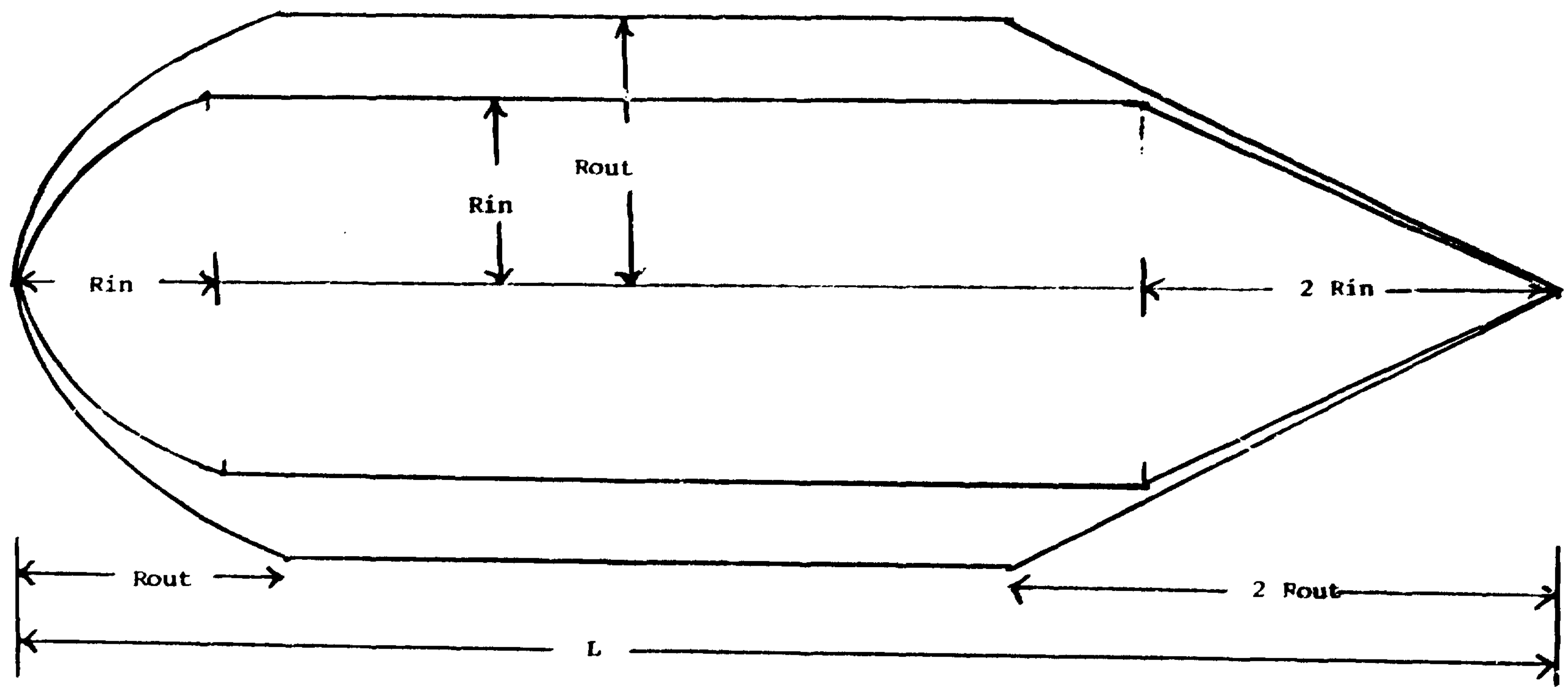

Figure 3: Idealized Envelope Shape

$$V_{in} = \pi L R_{in}^2 - 5\pi R_{in}^3/3$$

$$A_{in} = 2\pi R_{in}(L - 3R_{in})$$

In these idealized geometries, volume and area are greater than typical airship envelopes for a given maximum diameter. The more important volume and area relationship, however, is very close. These relationships are used because of their simplicity, allowing quick computer iterations, and the variation in manufactured airship envelope shapes and their corresponding geometric relationships.

B. CONDUCTION AND CONVECTION MODELLING

1. Conduction Through the Envelopes

Since the dimensions of the airship are very large compared to the thickness (t) of the envelopes, a one dimensional heat conduction equation is completely valid (reference 8, ch. 1):

$$q = -(kA/t)(T_{out} - T_{in})$$

The envelope thickness is idealized as a homogeneous material, although Vadala, in reference 2, clearly expects a multilayered fabric composite, such as a Kevlar base with covering Mylar films. The thermal conductivity (k) values used in this model are derived from reference 9 based on properties of Kevlar fabric in an appropriate thickness of .05 in.

$$k = 0.03266 \text{ BTU ft/hr ft}^2 \text{ F}$$

2. External Convection

Depending on operating conditions, the external flow will meet the criteria for forced, mixed, or free convection heat transfer conditions. In this approach, only forced and free convection values are derived, and a curve is sketched between zero and ten knot forced velocity values to represent the mixed convection regime.

Operationally, this regime is expected to prove very important, as heat up and cool down periods will be required on takeoff and landing, depending on airship loading. With the airship tethered, light winds or even eddy currents in relatively calm air, with the boundary layer effects of the earth's surface, are assumed to make a direct analysis of this regime inaccurate. Therefore, even though a limited analysis of this mixed flow regime is possible, only the rough curvefit is used in the present model.

For the free convection condition, the airship is idealized as a horizontal cylinder of equivalent area, and equation 7-36 from reference 8 is chosen as the closest empirical fit to the physical conditions:

$$Nu_f = hL/k$$

$$= \{0.6+0.387[Gr_d Pr/[1+(.559/Pr)^{9/16}]^{16/9}]^{1/6}\}^2$$

where: k, μ, ρ, Pr, and Gr are based on the fluid temperature,

$$T_f = (T_5 + T_{inf})/2$$

and Gr_d is based on the maximum diameter of the airship (see the temperature profile, Figure 4).

Under forced convection conditions, the airship external surface is idealized as a simple flat plate with the equivalent length of the airship and the area of the outer envelope. Equations 5-79 and 5-83 of reference 8 are manipulated to yield the average equivalent convective heat transfer coefficient:

$$h = (k/L)Re_L Pr^{1/3}\{[.2275/(\log Re_L)^{2.584}] - [850/Re_L]\}$$

assumptions are:

- laminar-turbulent boundary layer transition occurs at $Re = 5x10^5$
- boundary layer is attached over the entire surface
- the additional three dimensional body of rotation effects at the nose and tail are neglected
- isothermal surface

The derived convective heat transfer coefficients are then substituted into the linear heat transfer equation:

$$q = hA(T_2 - T_1).$$

3. <u>Free Convection Between the Envelopes</u>

Here, due to the limitations of empirical data, the rough idealization of concentric horizontal cylinders is used. Equations 7-60 through 7-63, again from reference 8, are the closest approximation to the physical model available. These equations are based on isothermal surfaces, and a constant spacing in the annulus between the

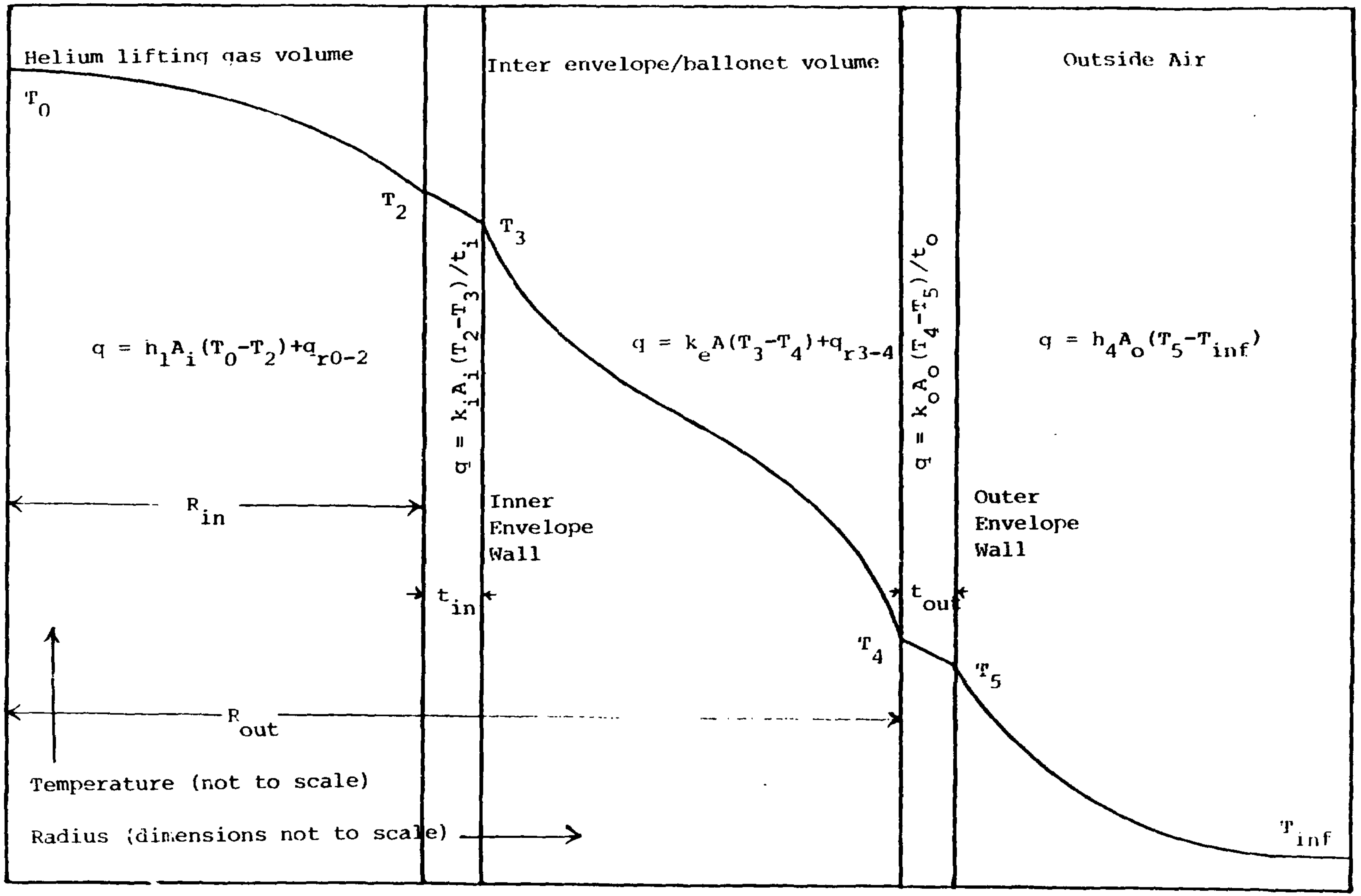

Figure 4: Temperature Profile

cylinders. A major problem here is that this empirical data is based on GrPr factors up to only 10^8. The airship model GrPr combination is on the order of 10^{11}. However, since $GrPr = 10^8$ is well into a turbulent convective boundary layer, it is assumed there are no significant changes up to $GrPr = 10^{11}$. Then:

$$k_e = k(0.4)[Gr_d Pr]^{0.2}$$

where: Gr_d is based on the spacing between the cylinders,

$$R_{out} - R_{in} = d$$

and the properties μ, ρ, k are evaluated at T_m

$$T_m = \text{the "volume mean" temperature}$$

$$= \{[(Rm^3 - R_{in}^3)T_3 + (R_{out}^3 - Rm^3)T_4]/[R_{out} - R_{in}]\}$$

$$Rm = (R_{in} + R_{out})/2$$

then: $q = 2\pi Lk_e(T_3 - T_4)/\ln(R_{out}/R_{in})$

4. Free Convection Inside the Inner Envelope

Modelling the convection in the inner envelope proves to be the most elusive problem. Empirical equations based on heat transfer from a uniform temperature fluid to a container wall are not adequate due to the additional convective turbulence in this volume gained from whatever heat source is used. Idealizing a heating duct and the envelope as concentric bodies results in Grashof numbers several orders of magnitude higher even than that between the envelopes. It is believed that completely different convective patterns will result, and that the application of

concentric body equations to this physical model is questionably accurate.

The most applicable heat transfer coefficient available for this model can be derived from Stefan's article on hot air balloons (reference 5). Although the convective activity for the airship heater or heat source is less violent than the open flame of the hot air balloon, the scale of convective activity is of the same order, and the heat transfer mechanisms at the envelope wall are assumed to be similar. Accordingly, Stefan's convective heat transfer coefficient, based on hot air balloon flight data, is adapted for the Helium in the airship by assuming

$$Nu = (\text{constant})(GrPr)^{n}$$

as in the standard empirical forms. The exponent, n, is approximated as 0.25, similar to the value used in the volume between the envelopes. Then the constant is cancelled by:

$$Nu_{He} = Nu_{air}\,(GrPr)_{He}^{0.25}\,/(GrPr)_{air}^{0.25}$$

and

$$h_{He} = k_{He}\,h_{air}\,[(\mu_{air}\,\rho_{He}/\mu_{He}\,\rho_{air})^{2}]^{0.25}\,/k_{air}$$

From reference 4,

$$h_{air} = [0.51\ \text{BTU/hr ft}^{2}\ R][T_0 - T_2]^{1/3}$$

and

$$q = h_{air}A(T_0 - T_2)$$

This approach results in values of h double that derived from the application of the standard empirical

equations previously referenced. It is believed to be most accurate due to the similarity of convective heating action and size scale.

Additional complications arise in this internal volume if a steam injection method is used as a heating source, as described in section II,B of this paper. Basic heat transfer texts such as references 8 and 10 discuss this difficult problem at length. Convective heat transfer will decrease due to the reduced temperature of wet steam from that of a simple liquid fuel heater, and a small insulative effect of the condensate film on the envelope is gained. The significant change, however, is seen when the heat of vaporization is transferred almost directly to the envelope wall during condensation. A direct estimate of the heat transfer characteristics is not attempted for this case, but data based on opposite extremes is obtained in section IV. The optimistic extreme is assumed as no increase in the heat transfer coefficient. The pessimistic extreme is the case where the envelope wall temperature is the same as mean fluid temperature (or an infinite heat transfer coefficient).

C. RADIATION HEAT TRANSFER

1. General

Initially, the low temperature expected in this airship would lead one to neglect the radiation heat transfer. The insulative effect of the inter-envelope air

space, however, reduces the convective heat loss to the order of the radiative heat loss between the envelopes for expected envelope emissivity values.

Envelope emissivity, then, becomes of primary importance. Developments in aerospace metallic coatings used to control temperature of satellites provides the promise of desired characteristics. Reference 11 discusses vacuum metallizing or solution processing techniques of depositing a thin metal coating onto mylar film which will result in an opaque metal thickness of 5×10^{-6} inches. This thickness results in about 25 pounds of Aluminum for each envelope surface coated, and emissivities less than 0.1.

The addition of the non-linear radiative heat transfer term in a set of linear equations becomes a major concern. Section D describes how the problem is handled in this model, and the problem of iteration convergence.

2. <u>Radiation to the Inner Envelope</u>

The straightforward solution of the radiative heat transfer between an enclosed body and the enclosing surface leads to equation 8-43 of reference 8:

$$q_r = \frac{\sigma A_{htr}(T_{htr}{}^4 - T_2{}^4)}{(1/\varepsilon_{htr}) + [A_{htr}/A_i][1/\varepsilon_i \quad - 1]}$$

where A_{htr}, T_{htr}, and ε_{htr} can be chosen appropriately. In the results section, from program HOTSHIP, these values are used pessimistically as:

A_{htr} = 500 ft^2

T_{htr} = 700 F

ε_{htr} = 0.1 (typical of metal surface)

and results are derived for a range of envelope emissivities.

Computations are more complex for steam injection. Strong absorption lines for the water vapor lead to calculations of radiative heat transfer based on the mean free path computations as shown in chapter 8 of reference 8, and in reference 6. Due to the absence of the heater with a high surface temperature, however, the total radiative loss is expected to be less with the steam injection. This computation is not completed in this model, and program HOTSHIP assumes the radiative heat loss to be the same for both heating methods.

3. Radiation Between the Envelopes

The greatest radiative heat loss problem is between the envelopes, due to the large radiative surface areas. Again, the enclosed body equation is used:

$$qr = \frac{\sigma\ A_{in}(T_3{}^4 - T_4{}^4)}{(1/\varepsilon_{in}) + [A_{in}/A_o][1/\varepsilon_o\ \ - 1]}$$

and results are obtained for envelope emissivities from 0 to 0.9.

4. Radiative Loss from the Outer Envelope

References 5 and 6 have a detailed treatment of radiation heat transfer between a hot balloon surface and

the surrounding environment. A direct application to this airship model can be made, but this is not completed for three reasons. First, from the high convective heat loss only, the external envelope temperature is normally within two degrees F of the outside air temperature. Second, the expected operational conditions of this airship are assumed to vary to extremes, and results from reference 5 show that radiative heat loss is highly variable in these conditions. Accounting for these variations is not considered appropriate or necessary in this initial model. Third, due to expected night and foul weather operations, the external envelope emissivity should be small, minimizing the external radiative heat loss. Under specified environmental conditions, program HOTSHIP can be modified to include this external radiation term.

D. THE RESULTING SET OF LINEARIZED EQUATIONS

Discretizing the temperature profile as in Figure 4, then, the linearized set of heat transfer equations becomes a linear system of five equations in five unknowns for this particular physical model.

At any surface,

$$q = q_{conv} + q_r$$

In the inner envelope, then,

$$q = q_{conv} + q_r$$

$$= h_1 A_i [T_0 - T_2] + \frac{\sigma A_{htr}(T_{htr}^4 - T_2^4)}{(1/\varepsilon_{htr}) + [A_{htr}/A_i][1/\varepsilon_i - 1]}$$

and to linearize, an initial value is substituted for T_2 in the q_r term, and q_r is treated as a constant in the linear system. Then,

$$q = h_1 A_i [T_0 - T_2) + q_{r0-2}$$

Similarly, between the envelopes,

$$q = \frac{2 \pi k_e L(T_3 - T_4)}{\ln (R_{out}/R_{in})} + \frac{\sigma A_{htr}(T_{htr}^4 - T_2^4)}{(1/\ _{htr}) + [A_{htr}/A_i][1/\ _i - 1]}$$

$$= \frac{2 \pi k_e L(T_3 - T_4)}{\ln(R_{out}/R_{in})} + q_{r3-4}$$

where initial values of T_3 and T_4 are substituted to make q_{r3-4} a constant in the system.

Rearranging terms, the resulting set of equations becomes:

$$\begin{aligned}
T_2 + \quad & q/h_1 A_i &= T_0 + (q_{r0-2})/h_1 A_i \\
T_2 - T_3 \quad & -q\, t_i/k_i A_i &= 0 \\
T_3 - T_4 \quad & -\frac{q \ln (Rout/Rin)}{2 \pi k_e L} &= -q_{r3-4}\frac{\ln(Rout/Rin)}{2 \pi k_e L} \\
T_4 - T_5 \quad & - q\, t_o/k_o A_o &= 0 \\
T_5 \quad & - q/h_4 A_o &= T_{inf}
\end{aligned}$$

In matrix form,

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 1/h_1 A_i \\ 1 & -1 & 0 & 0 & -t_i/k_i A_i \\ 0 & 1 & -1 & 0 & -\frac{\ln(Rout/Rin)}{2 \pi k_e L} \\ 0 & 0 & 1 & -1 & -t_o/k_o A_o \\ 0 & 0 & 0 & 1 & -1/h_4 A_o \end{bmatrix} \begin{bmatrix} T_2 \\ T_3 \\ T_4 \\ T_5 \\ q \end{bmatrix} = \begin{bmatrix} T_0 + (q_{r0-2})/h_1 A_i \\ 0 \\ -q_{r3-4}\frac{\ln(Rout/Rin)}{2 \pi k_e L} \\ 0 \\ T_{inf} \end{bmatrix}$$

When this linear system is solved, these new solutions are resubstituted into the equations to find the heat transfer coefficients and radiative heat transfer values for the new iteration. This entire problem is iterated until convergence for q is obtained.

Since several of the "constants" in the linearized system depend on the temperatures (R_{in}, h_1, h_4, and k_e) and particularly since the radiative heat transfer terms are fourth order in temperature, convergence of this iteration is expected to be a major problem. A close initial quess of the temperature values, however, produces convergence up to critical envelope emissivity values of more than 0.9. This is considered an adequate range for emissivities, and an adequate solution for this model.

E. THE COMPUTER PROGRAM

Program HOTSHIP utilizes these equations and completes the iterations with a convergence criterion of q within 0.1 BTU/sec. From input values of airship velocity, T_{inf}, T_0 and envelope emissivities, the temperature profile and heat loss rate are computed. From these values, the increase in lift and equivalent fuel burn rate are directly computed.

Properties of air and Helium with little temperature dependence are evaluated by a linear interpolation from tabulated values obtained from reference 8. The ideal gas equation is used in density change computations based on

tabulated values at an intermediate temperature. A series of linear interpolations in Subroutine Volume is used to evaluate the specific volume of steam at a given temperature based on tabulated values from reference 12. Standard atmospheric pressure (14.7 psi) is used in all calculations.

Since the linearized system of equations is of the simple form

$$\begin{bmatrix} 1 & 0 & 0 & 0 & A \\ 1 & -1 & 0 & 0 & -B \\ 0 & 1 & -1 & 0 & -C \\ 0 & 0 & 1 & -1 & -D \\ 0 & 0 & 0 & 1 & -E \end{bmatrix} \begin{bmatrix} T_2 \\ T_3 \\ T_4 \\ T_5 \\ q \end{bmatrix} = \begin{bmatrix} T_0 + Aq_{r0-2} \\ 0 \\ -Cq_{r3-4} \\ 0 \\ T_{inf} \end{bmatrix}$$

a simple algebraic solution is used in the program for q, and then a substitution of new values is used to evaluate the temperature for the new iteration.

Special computations are made if airship velocity or envelope emissivities are zero to avoid division by zero problems in the program. Results for airship velocities less than ten knots (but not zero) are less than accurate values due to the mixed convection conditions over the outer envelope.

Equivalent fuel flow rate is based on 20500 BTU of useable heat energy per pound of fuel, which is obtainable from petroleum base fuels. Increase in lift due to heating without steam injection is based on the sum from the volume

expansion of a fixed mass of Helium and the decrease in density of the air volume between the envelopes:

$$m_f(\text{lbm}) = q(\text{BTU})/20500(\text{BTU/lbm})$$

$$\text{change in lift (lbf)} = \frac{(T_o - T_{inf})}{T_{inf}}\,130{,}000 + (V_{out} - V_{in})\frac{(T - T_{inf})}{T_{inf}}$$

When steam injection is used to heat the inner volume, significant lift is produced by the volume the saturated steam displaces. Since the weight of the water is unchanged when it is vaporized, the change in lift produced by the steam is:

$$\text{change in lift (steam) (lbf)} = \text{change in } V_{steam}\rho_{inf}$$

where V_{steam} is the increase in steam volume from initial (T_{inf}) to heated (T_0) conditions. This volume is calculated for a specified temperature from:

$$V_{steam} = V_{in}T\,R/[18.02(spv)p-RT]$$

using the ideal gas equation for Helium and steam table values from Subroutine Volume for the steam.

The loss of air spacing between the envelopes due to the additional inner volume from the steam is not accounted for by the program.

Output quantities are filed for use by the IBM graphics program DISSPLA.

IV. RESULTS

A. PROGRAM OUTPUT DATA

Figures 5 through 10 show the program HOTSHIP results graphically for the parameters of interest. All results shown are for ambient air temperature of 60 deg F. Certainly this airship concept will have the same response to atmospheric temperature and density changes as a standard airship. An additional minor effect will be the change in the inner envelope radius required to hold the same gross lift, which changes the insulative gap between the envelopes.

It is quickly seen from Figures 5 through 7 that envelope emissivities will make a dramatic difference in heat loss. For organic materials, with emissivities greater than 0.9, the total heat loss rate is six or more times the convective heat loss alone ($\mathcal{E} = 0.0$). Even with envelope emissivity of 0.1, the radiative and convective heat losses are on the same order.

The curve for the specific results of $\mathcal{E}_{in} = 0.1$ and $\mathcal{E}_{out} = 0.9$ is shown, which is expected to correspond closely to the special case where the inner envelope only is vacuum metallized. Note that the heat loss for this case is less than if both envelopes have an emissivity of 0.2.

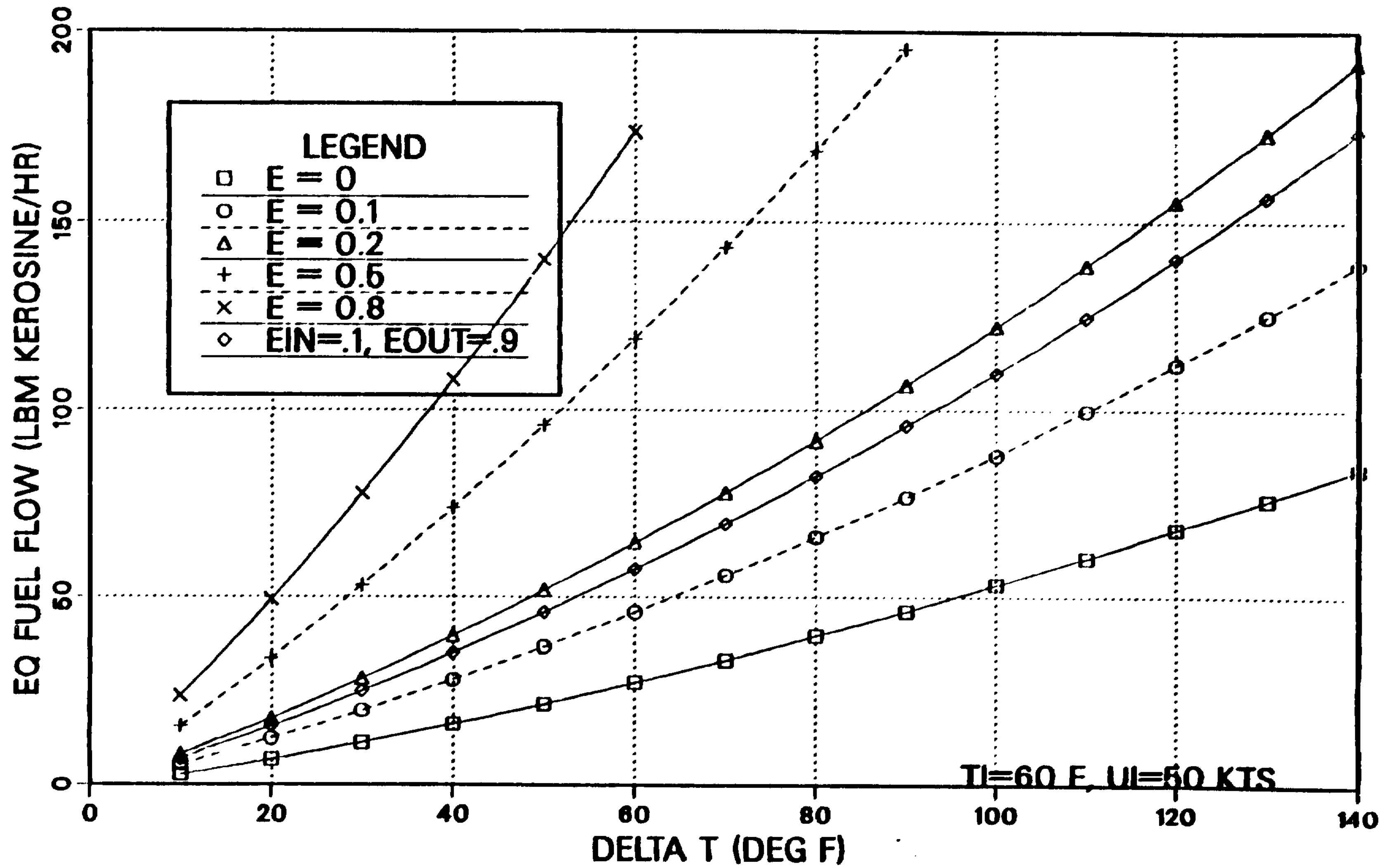

Figure 5: Eq Fuel Flow vs Delta T

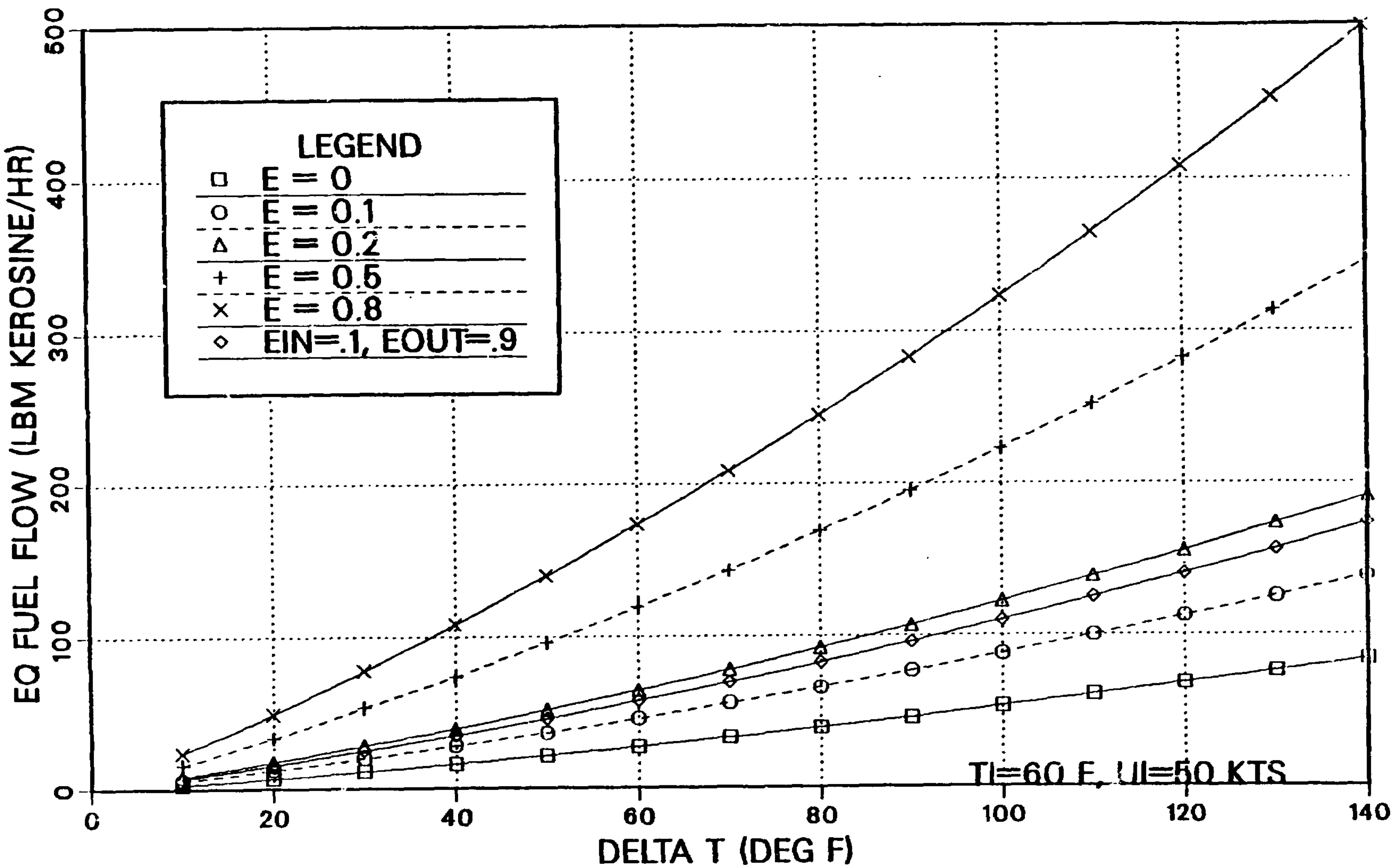

Figure 6: Eq Fuel Flow vs Delta T (large scale)

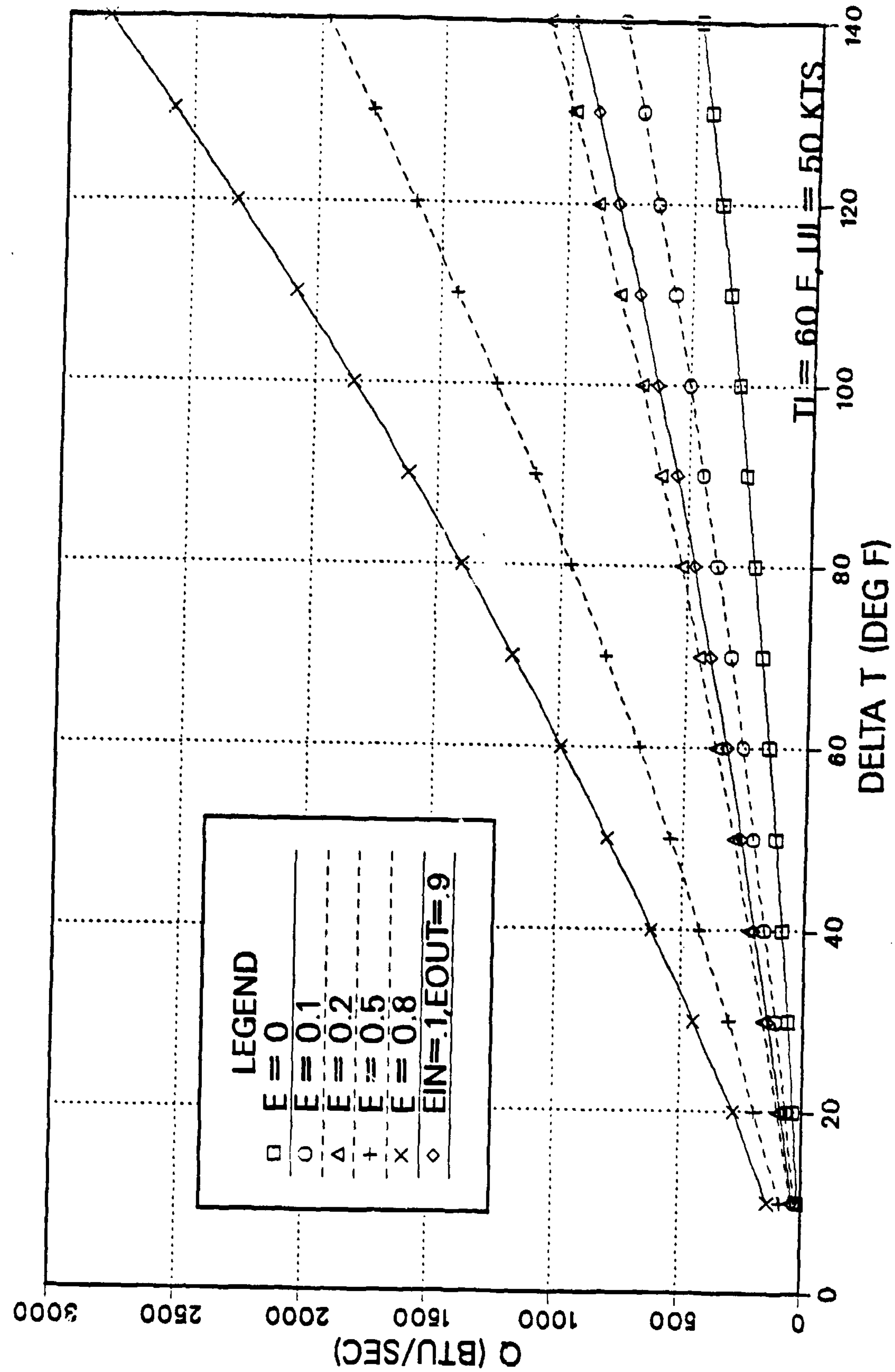

Figure 7: Q vs Delta T

Although some heat loss resistance is exhibited at the boundary layers on the inside and outside, the results file in Appendix B clearly shows that the inter-envelope volume provides most of the insulative effects. More than 8/10 of the temperature drop is seen across this air gap under "normal" cruise conditions, implying that the heat loss would be several times higher in a conventional airship design. In fact, if the matrix value "C" is set to zero in program HOTSHIP, the heat flux is seen to increase by a factor of 8.4 (see Appendix B). This result does not account for the additional radiative heat loss which will occur due to the significant temperature increase of the outer envelope.

This insulative gap is seen to be particularly critical as airship speed is increased from zero. Figure 10 shows that the heat flux quickly rises to an asymptotic value about twice that for zero velocity even in the concept design. This rise would be accentuated by the appropriate factor of more than eight without the inter envelope space. This implies that a standard airship moving at 50 knots will have an order of magnitude higher heat loss than a hot air balloon with the same shape and size, and 17 times the heat loss of the concept design at zero velocity.

Figures 8 and 9 show a dramatic difference in lift increase (for the same heat input) when the steam injection heating concept is used. The volume increase due to water

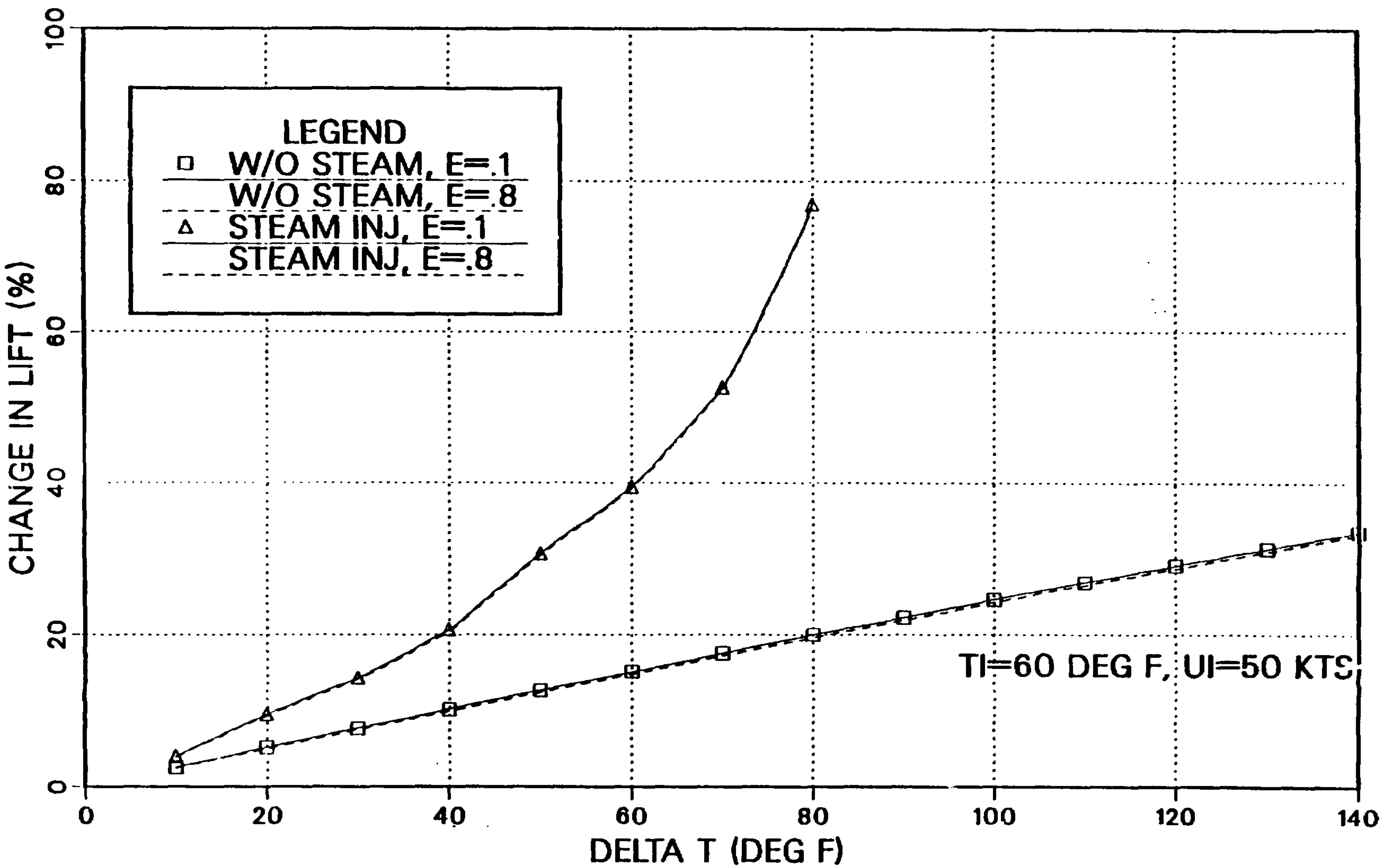

Figure 8: Change in Lift vs Delta T

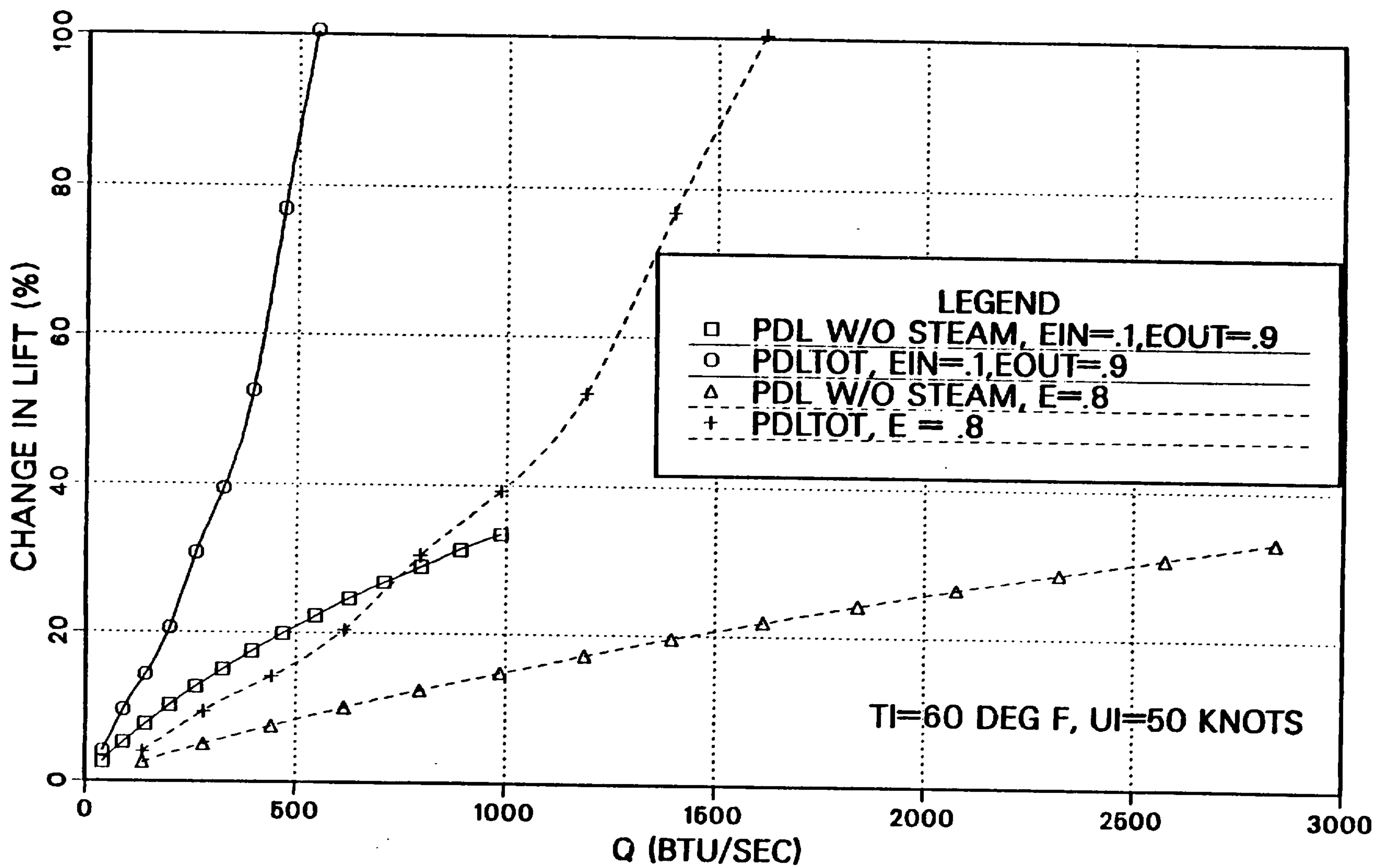

Figure 9: Change in Lift vs Q

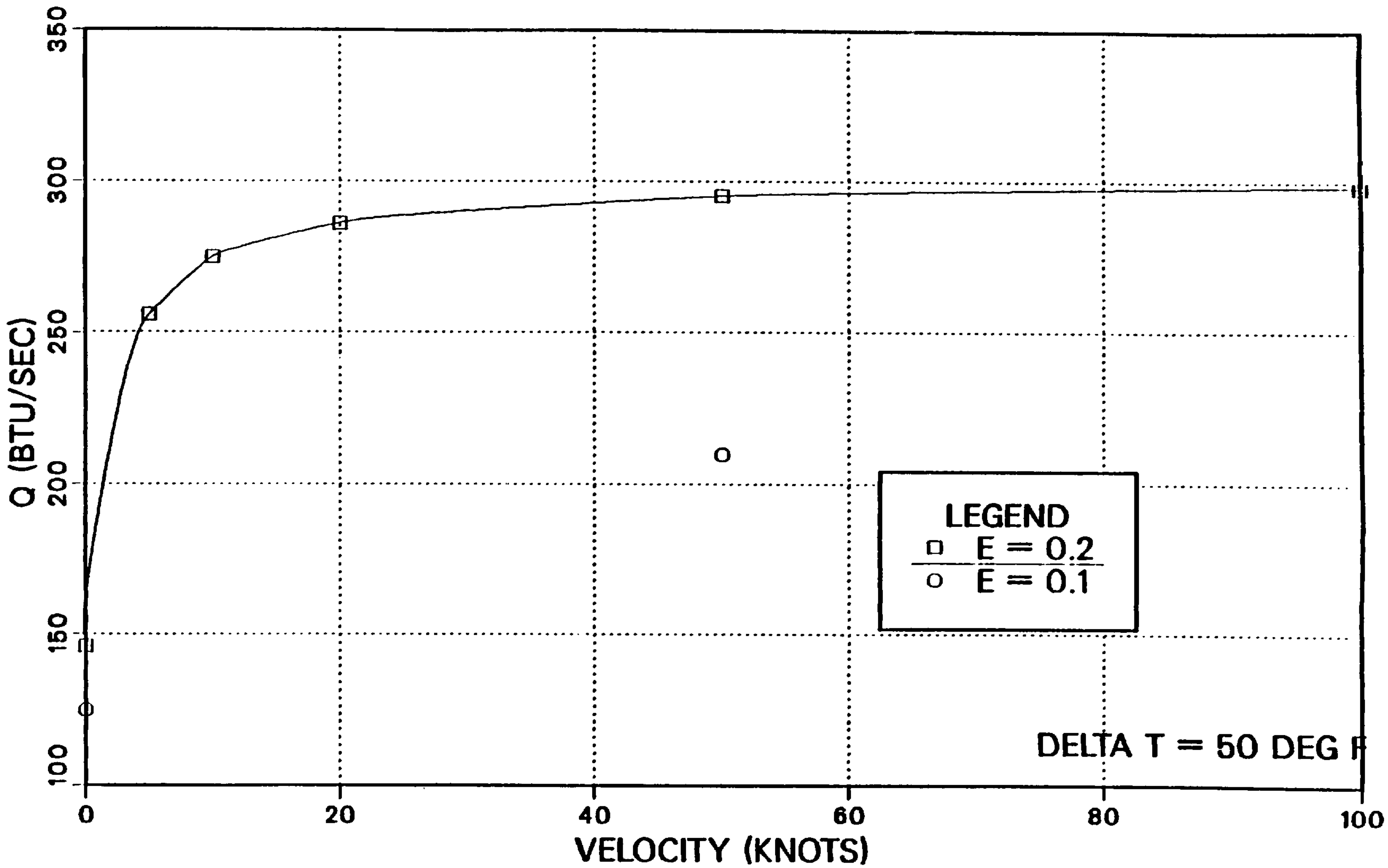

Figure 10: Q vs Velocity

vapor at saturation level in the Helium becomes more and more rapid as temperature is increased. As previously noted, the loss of insulative space from the water vapor volume is not accounted for in program HOTSHIP, and the heat loss rates shown are increasingly optimistic with temperature rise. This effect is not more than a few percent at 120 deg F (delta T = 60) but by 160 deg F, the inner volume would be greater than the outer volume, implying that by this point the inter envelope insulative effect is absent, and the heat flux will actually be many times higher as shown previously in this section.

If losses due to condensation on the inner envelope are much higher than expected, the pessimistic approximation of $T_2 = T_0$ is made by setting the matrix value of "A" to zero. Results in Appendix B show only a 12.9% increase in heat loss for this condition.

B. ESTIMATES OF ACCURACY

The best accuracy is obtained from the conduction equations in the envelope materials. For the material described, the conductivity is estimated to be within 20% of the average of that to be obtained in an actual envelope. The one dimensional conduction equation is completely applicable. Unfortunately, this is among the least critical conditions due to the ineffective insulation of the envelopes. Even if the conductivity of the envelopes was halved, the effect on heat loss is minor. In Appendix B,

for a test point at T_{inf}=60 F, U_{inf}=50 knots, T_0=110 F (delta T = 50 F), ε_{in}=0.1, and ε_{out}=0.9, the HOTSHIP q results show a 4% decrease from the original condition. If the envelope heat loss resistance is increased by a factor of 10, a 24% reduction in q is obtained.

For external forced convection, the flat plate approximation is not expected to be more than 10% off. Separation of the boundary layer over the aft section of the airship may result in less heat loss than expected. Again, though, for forced convection conditions, q is changed very little (2%) even if the convective heat transfer coefficient is infinitely large.

With free convection between the envelopes, the isothermal concentric cylinder idealization may be very optimistic. Additionally, the large scale involved may result in convective patterns much different than those present in the data from which the empirical equations were derived. If the inner envelope is anchored at the bottom, with control over the shape as in Figures 1 and 2, the error in the convective coefficient is expected to be as much as, but not greater than, 50%.

The inner envelope coefficient, derived from hot air balloon flight data, was modified to apply to Helium. Also, convective turbulence as well as the envelope shapes will be quite different. The value used is considered to be pessimistic, and not more than 25% in error.

The radiation equations are basically analytical, and should be accurate to within the uncertainties in emissivities and temperatures.

Overall unknown factors include additional conductive and convective losses in the lower portion of the airship due to the anchoring of the inner envelope, and losses in ducting and structural components.

Although the combination of these uncertainty factors is:

$$(1.2)(1.4)(1.5)(1.25) = 3.15$$

the major factor is the convection between the envelopes. It is believed that an airship constructed as conceived will have convective heat losses well within a factor of two times these results. Radiative heat losses, restricted to the assumptions stated, will be within a few percent of these results.

V. CONCLUSIONS

For this relatively simple concept design, heat loss is small enough to allow large changes in lift by heating the lifting gas with engine waste or exhaust heat or small liquid fuel furnaces. For envelopes with low emissivities produced as discussed, these results, and Appendix C calculations show that more than a 30% increase might be expected by use of engine waste heat alone under moderate power conditions. If steam injection is used, a 100% increase might be expected, with a significant time and fuel penalty required for evaporating the required amount of steam.

By using heated gas, vectored thrust, dynamic lift and/or other lift augmentation systems, the airship as conceived might achieve more than a 100% increase in lift, which will allow a tremendous operational flexibility in cargo load capacity, unrefueled range and endurance and mission equipment carried. Obvious advantages over rotary wing aircraft in load carrying capacity include a much larger weight capacity, low fuel useage, longer range, and no rotor blast effects on takeoff or landing. Advantages over fixed wing aircraft are vertical landing and takeoff and lower fuel useage.

This concept has several significant disadvantages:

- The double envelope will be heavier than conventional airship envelopes, although this factor is mitigated by not requiring additional ballonet envelopes.

- A detailed design for the suspension and shape control of the envelopes has not been completed or tested.

- Hot air ducting and/or a liquid fuel furnace will add weight to the basic airship.

- A steam injection heating method requires a lot of water (14000 lb), energy to heat that water (7.32×10^6 BTU for a 50 deg F temperature rise = 360 lbm fuel), pays a weight penalty for the liquid film on the inner envelope (about 7000 lb), and requires some type of recovery system.

- Availability, toughness, and cost of a low emissivity fabric coating are unknown factors.

- Some time is required for heatup or cool down during takeoff and landing operations where load changes are significant, depending on heating method used and heat source.

Overall, the promise of operational flexibility and capability should lead to an expanded study of this concept, with the effort and financing required to accomplish large scale testing to prove the estimated and unknown design factors, and solve those engineering and conceptual problems which will arise.

APPENDIX A

PROGRAM HOTSHIP

The following FORTRAN program, as described in the text, is used to iterate the linearized heat transfer system of equations. Program inputs are U_{inf}, air temperature, and envelope emissivities. Several outputs, including the heat flux, q, and temperature profile values, are written to the screen and to files for use with the graphics program used to compile figures 5 through 10.

```
C     THIS PROGRAM ITERATES A LINEAR HEAT TRANSFER MODEL OF AN AIRSHIP
C     TO SOLVE FOR THE TEMPERATURE PROFILES AND THE RATE OF HEAT TRANSFER

      REAL MUI,MUMN,H1,H4,KMEAN,KINF,KEQV,KIN,KOUT,GRD,KFL,MUFL,GRFL
      REAL KHE,KAIR,MUAIR,MUHE,LH2O,MH2O,H1AIR

C     INPUTS ARE:  THE ENVELOPE EMISSIVITIES, VELOCITY, AND AIR TEMP
      PI=3.1415927
10    PRINT*,'DO YOU WANT TO INCLUDE THE RADIATION HEAT TRANSFER'
      PRINT*,'EFFECTS?(1=YES, 2=NO)'
      READ*, Y

      IF (Y.EQ.2.0) GO TO 20
      PRINT*, 'INPUT THE EMISSIVITIES OF THE INNER AND OUTER'
      PRINT*, 'ENVELOPES, EIN AND EOUT'
      READ*, EIN,EOUT

 20   PRINT *,'INPUT U INFINITY (UI,KTS), AND T INF (DEG R)'
      READ *, UI,TI

C     COMPUTING THE DIMENSIONS OF THE INNER ENVELOPE
C     WITH THESE GIVEN OUTER ENVELOPE DIMENSIONS
      VTOT=4.0E6
      ROUT=66.5
      AOUT=1.4213E5
      L=398.9

C     THIS LOOP INCREMENTS THE HELIUM TEMP IN 10 DEG STEPS
      DO 1200 K=1,14
      TO=TI+10.0*K
      M=1
      VIN=2.0E6*TO/520
      RINIT=50.0
100   RTRY=(-3.0*VIN/(5.0*PI*(RINIT-3.0*L/5.0)))**0.5
      IF (ABS(RTRY-RINIT).LE.0.001) GO TO 200
      RINIT=RTRY
      IF (M.GE.20) GO TO 200
      M=M+1
      GO TO 100
200   RIN=RTRY

      AIN= 2.0*PI*RIN**2+2.0*PI*RIN*(L-3.0*RIN)+PI*(RIN**2)*2.236068

C     SPECIFYING THE PARAMETERS OF THE ENVELOPE MATERIALS

      KIN=0.03266/3600.0
      THIN=0.05/12.0
      KOUT=KIN
      THOUT=THIN
C     IF UI=0, THEN FREE CONVECTION CONDITIONS EXIST
      IF (UI.EQ.0.0) GO TO 400
```

```
C     FORCED CONVECTION PARAMETERS OUTSIDE THE AIRSHIP, BASED ON A
C     CRITICAL REYNOLDS NUMBER RECRIT=500000
      RHOI=0.0022846*540.0/TI
      MUI=((4.3339E-7-3.85605E-7)/90.0)*(TI-540.0)+3.85605E-7
      REL=RHOI*UI*6076.0*L/(MUI*3600.0)
      PRI=((.697-.708)/90.0)*(TI-540.0)+.708
      KINF=(((.0173513-.0151615)/90.0)*(TI-540.0)+.0151615)/3600.0

      H4=((0.2275/((LOG10(REL))**2.584))-850.0/REL)*KINF*REL*
     +(PRI**0.333333333)/L

C     SETTING THE INITIAL VALUES FOR THE LINEAR SYSTEM ITERATION

400   T2=T0-(T0-TI)/5.0
      T3=T0-(T0-TI)/4.5
      T4=T0-(T0-TI)*4.0/5.0
      T5=T0-(T0-TI)*4.5/5.0
      DQDT=480
      EHTR=0.1
      AHTR=500
      THTR=700

      J=1

      IF (UI.NE.0.0) GO TO 600
C     IF EXTERNAL FLOW IS FREE CONVECTION, COMPUTE THE HEAT TRANSFER
C     COEFFECIENT FOR UI=0, IF NOT, H4 IS ALREADY COMPUTED

500   TFL=(T5+TI)/2
      PRFL=((.697-.708)/90.0)*(TFL-540.0)+.708
      KFL=(((.0173513-.0151615)/90.0)*(TFL-540.0)+.0151615)/3600.0
      MUFL=((4.3339E-7-3.85605E-7)/90.0)*(TFL-540.0)+3.85605E-7
      RHOFL=0.0022846*540.0/TFL
      GRFL=32.174*(T5-TI)*8.0*(ROUT**3)*(RHOFL**2)/(TFL*(MUFL**2))

      H4=(KFL/L)*((.6+.387*(GRFL*PRFL/(1.0+(.559/PRFL)**.5625)**1.7778)
     +**.1666667)**2)

C     FREE CONVECTION BETWEEN THE ENVELOPES BASED ON HORIZONTAL
C     CYLINDRICAL ANNULUS, ISOTHERMAL ENVELOPES, AND CONSTANT
C     ENVELOPE SPACING

600   RMEAN=(ROUT+RIN)/2.0
      TMEAN=(((RMEAN**3)-(RIN**3))*T3+((ROUT**3)-(RMEAN**3))*T4)/
     +((ROUT**3)-(RIN**3))
      PHOMN=0.0022846*540.0/TMEAN
      MUMN=3.85605E-7+((4.3339E-7-3.85605E-7)/90.0)*(TMEAN-540.0)
      PRMN=0.708+((.697-.708)/90.0)*(TMEAN-540.0)
      KMEAN=(0.0151615+((.0173513-.0151615)/90.0)*(TMEAN-540.0))/3600.0
      GRD=32.174*(T3-T4)*((ROUT-RIN)**3)*(RHOMN**2)/(TMEAN*(MUMN**2))
```

```
      KEQV=0.4*KMEAN*((GRD*PRMN)**0.2)

C     FREE CONVECTION PARAMETERS IN THE INNER ENVELOPE
C     UTILIZING HOT AIR BALLOON DATA FOR H

      H1AIR=((T0-T2)**0.333333333)*1.4167E-4
      THE=(T0+T2)/2
      MUAIR=((4.3339E-7-3.85605E-7)/90.0)*(THE-540.0)+3.85605E-7
      RHOAIR=0.0022846*540.0/THE
      KAIR=(.0151615+((.0173513-.0151615)/90.0)*(THE-540.0))/3600.0
      KHE=(.0784075+((.097706-.0784075)/199.0)*(THE-459.0))/3600.0
      MUHE=(.37951E-6+((.48143E-6-.37951E-6)/199.0)*(THE-459.0))
      RHOHE=(.00036954*459.0/THE)

      H1=(KHE*H1AIR/KAIR)*((MUAIR*RHOHE/(MUHE*RHOAIR))**0.5)

C     SETTING UP THE SYSTEM OF EQUATIONS FOR ITERATION
C     BY INITIALIZING AND SPECIFYING THE QR VALUES

      DQDTR0=0.0
      DQDTR3=0.0
      IF (Y.EQ.2.0) GO TO 700

      DQDTR0=0.1714E-8*AHTR*((THTR**4)-(T2**4))/(((1.0/EHTR)+
     +(AHTR/AIN)*((1.0/EIN)-1.0))*3600)

      DQDTR3=0.1714E-8*AIN*((T3**4)-(T4**4))/(((1.0/EIN)+
     +(AIN/AOUT)*((1.0/EOUT)-1.0))*3600)

700   A=1.0/(H1*AIN)
      B=1.0*THIN/(KIN*AIN)
      C=1.0*(LOG(ROUT/RIN))/(2.0*PI*L*KEQV)
      D=1.0*THOUT/(KOUT*AOUT)
      E=1.0/(H4*AOUT)

800   SUM=A+B+C+D+E
      DELT=T0-TI

C     FROM AN ALGEBRAIC SOLUTION OF THE SYSTEM, Q IS FOUND AS:
C     THEN THE TEMPERATURE VALUES ARE FOUND
      DQDTN=(DELT+A*DQDTR0+C*DQDTR3)/SUM
      T2=T0-A*(DQDTN-DQDTR0)
      T3=T2-B*DQDTN
      T4=T3-C*(DQDTN-DQDTR3)
      T5=T4-D*DQDTN

C     CONDITIONS FOR STOPPING THE SYSTEM ITERATIONS ARE SPECIFIED
      IF (J.GE.99) GO TO 1000
      J=J+1
      IF ((ABS(DQDTN-DQDT)).LE.0.1) GO TO 1000
```

```
      DQDT=DQDTN
      IF (UI.EQ.0.0) GO TO 500
      GO TO 600
1000  CONTINUE
C     EQUIVALENT FUEL BURN RATE AND LIFT CHANGE VALUES ARE
C     DIRECTLY COMPUTED

      DMDT=DQDTN*3600.0/20500.0

      DLIFT=130000.0*((DELT/TI))+((TMEAN-TI)/TI)*(VTOT-VIN)*RHOMN
     +*32.174
C     VALUES BASED ON STEAM INJECTION HEATING ARE COMPUTED
      PDL=DLIFT*100.0/130000.0

      CALL VOLUME (TI,SPVI)

      VH2OI=VIN*TI*1545.0/(18.02*SPVI*14.7*144.0-1545.0*TI)

      CALL VOLUME (TO,SPVO)

      VH2OH=VIN*TO*1545.0/(18.02*SPVO*14.7*144.0-1545.0*TO)

      DVH2O=VH2OH-VH2OI

      DLH2O=DVH2O*RHOI*32.174-(VH2OH*(TMEAN-TI)*RHOMN*32.174)/TI
      DLTOT=DLIFT+DLH2O
      PDLTOT=(DLTOT*100.0)/130000.0

C     PROGRAM OUTPUTS ARE PRINTED; FILES FOR GRAPHICS USE ARE WRITTEN

      WRITE (*,1110) M,J
      WRITE (*,1120) DQDTN,DMDT
      WRITE (*,1130) RIN, AIN
      WRITE (*,1140) VIN, DVH2O
      WRITE (*,1150) PDL, PDLTOT
      PRINT*, 'THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:'
      WRITE (*,1100) TO,T2,T3,T4,T5
      PRINT*, 'THE MATRIX VALUES A,B,C,D,E ARE:'
      WRITE (*,1160) A,B,C,D,E
      WRITE (*,1180) DQDTRO, DQDTR3, DQDTN

      WRITE(1,1100) UI,TO,DELT,DMDT,PDL,PDLTOT,EIN
      WRITE(2,1100) UI,TO,DELT,DQDTN,PDL,PDLTOT
      WRITE(3,1100) TO,T2,T3,T4,T5,TI,EIN
      WRITE(4,1100) TO,DELT,EIN,DQDTN,DMDT,PDL
1100  FORMAT(F8.2,T10,F8.2,T20,F8.2,T30,F8.2,T40,F8.2,T50,F8.2,T60,F8.2)
1110  FORMAT(1X,'NUMBER OF ITERATIONS ARE:RIN',I2,' ,FOR Q  ',I2)
1120  FORMAT(1X,'DQDTN = ',F10.2,'  DMDT = ',F10.2)
1130  FORMAT(1X,'RIN   = ',F10.2,'  AIN  = ',F11.2)
1140  FORMAT(1X,'VIN   = ',F10.2,' DVH2O = ',F11.2)
```

```
1150  FORMAT(1X,'PDL    = ',F10.2,' PDLTOT= ',F11.2)
1160  FORMAT(1X,F8.6,T11,F8.6,T21,F8.6,T31,F8.6,T41,F8.6)
1180  FORMAT(1X,'DQDTR0 = ',F7.2,'  DQDTR3 = ',F7.2,'  DQDTN = ',F7.2/)

C     THE PROGRAM IS RUN FOR OTHER INPUT VALUES IF DESIRED
1200  CONTINUE
      PRINT*
      PRINT*
      PRINT*, 'DO YOU WANT TO ENTER OTHER VALUES OF UI,TI,EIN OR EOUT?'
      PRINT*, '(1=YES, 2=NO)'
      READ*, Z
      IF (Z.EQ.1.0) GO TO 10
      STOP
      END

      SUBROUTINE VOLUME (T,SPV)
C     THIS SUBROUTINE USES A SERIES OF LINEAR APPROXIMATIONS TO '
C     COMPUTE THE SPECIFIC VOLUME OF STEAM AT 1 ATMOSPHERE AT TEMP=T

      IF (T.LE.530.0) THEN
         SPV=2445.0+(T-500.0)*(867.7-2445.0)/30

      ELSEIF (T.LE.560.0) THEN
         SPV=867.7+(T-530.0)*(350.0-867.7)/30

      ELSEIF (T.LE.590.0) THEN
           SPV=350.0+(T-560.0)*(157.17-350.0)/30

      ELSEIF (T.LE.620.0) THEN
           SPV=157.17+(T-590.0)*(77.23-157.17)/30

      ELSEIF (T.LE.650.0) THEN
           SPV=77.23+(T-620.0)*(40.95-77.23)/30

      ELSE
          SPV=40.95+(T-650.0)*(23.15-40.95)/30

      ENDIF

      END
```

APPENDIX B

PROGRAM SAMPLE OUTPUTS

The following program outputs are used to derive the values quoted in the results and conclusions chapters. These are divided into the following sections:

- Section 1: Values obtained from the basic program.
- Section 2: Values obtained for $T_2 = T_0$ by setting "A" to zero in the program.
- Section 3: Values obtained for $T_3 = T_4$ by setting "C" to zero in the program.
- Section 4: Values obtained for $T_5 = T_{inf}$ by setting "E" to zero in the program.
- Section 5: Values obtained for increased envelope heat loss resistance by factors of 2 and 10.

Units applicable to these data are:

- Distances/lengths in ft.
- Volumes in ft^3; Areas in ft^2.
- Heat flux in BTU/sec.
- Fuel flow rate in lbm/hr.
- Temperature in degrees R.

SECTION 1: VALUES OBTAINED FROM THE BASIC PROGRAM

```
INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   8
DQDTN =       41.16  DMDT =        7.23
RIN   =       45.75  AIN  =   102801.46
VIN   = 2115384.62 DVH2O =    25472.64
PDL   =        2.57 PDLTOT=        3.98
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00    548.80    548.61    540.29    540.16
THE MATRIX VALUES A,B,C,D,E ARE:
0.031986 0.004468  0.549943  0.003231  0.003923
DQDTR0 =     3.54  DQDTR3 =    26.04  DQDTN =   41.16

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =       89.71  DMDT =       15.75
RIN   =       46.22  AIN  =   103737.93
VIN   = 2153846.15 DVH2O =    79283.17
PDL   =        5.14 PDLTOT=        9.50
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00    557.76    557.36    540.64    540.35
THE MATRIX VALUES A,B,C,D,E ARE:
0.025960 0.004427  0.471630  0.003231  0.003923
DQDTR0 =     3.40  DQDTR3 =    54.26  DQDTN =   89.71

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =     143.07  DMDT =       25.12
RIN   =       46.68  AIN  =   104666.37
VIN   = 2192307.69 DVH2O =   121494.44
PDL   =        7.67 PDLTOT=       14.32
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00    566.80    566.17    541.02    540.56
THE MATRIX VALUES A,B,C,D,E ARE:
0.022918 0.004388  0.428758  0.003231  0.003923
DQDTR0 =     3.24  DQDTR3 =    84.42  DQDTN =  143.07

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =     200.58  DMDT =       35.22
RIN   =       47.15  AIN  =   105586.99
VIN   = 2230769.23 DVH2O =   192264.72
PDL   =       10.18 PDLTOT=       20.63
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 580.00    575.87    575.00    541.44    540.79
```

```
THE MATRIX VALUES A,B,C,D,E ARE:
0.020918 0.004350  0.399194  0.003231  0.003923
DQDTRO =    3.08  DQDTR3 =  116.51  DQDTN =  200.58

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      262.07  DMDT =       46.02
RIN   =       47.61  AIN  =   106500.01
VIN   = 2269230.77 DVH2O =   333175.90
PDL   =       12.65 PDLTOT=       30.69
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 590.00   584.95   583.82   541.87   541.03
THE MATRIX VALUES A,B,C,D,E ARE:
0.019469 0.004312  0.376496  0.003231  0.003923
DQDTRO =    2.92  DQDTR3 =  150.64  DQDTN =  262.07

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      327.36  DMDT =       57.49
RIN   =       48.07  AIN  =   107405.63
VIN   = 2307692.31 DVH2O =   453004.31
PDL   =       15.10 PDLTOT=       39.47
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 600.00   594.05   592.65   542.34   541.28
THE MATRIX VALUES A,B,C,D,E ARE:
0.018332 0.004276  0.358000  0.003231  0.003923
DQDTRO =    2.74  DQDTR3 =  186.84  DQDTN =  327.36

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      396.42  DMDT =       69.61
RIN   =       48.53  AIN  =   108304.04
VIN   = 2346153.85 DVH2O =   655969.36
PDL   =       17.51 PDLTOT=       52.59
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 610.00   603.15   601.47   542.84   541.56
THE MATRIX VALUES A,B,C,D,E ARE:
0.017400 0.004241  0.342319  0.003231  0.003923
DQDTRO =    2.55  DQDTR3 =  225.15  DQDTN =  396.42

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      469.23  DMDT =       82.40
RIN   =       48.98  AIN  =   109195.42
VIN   = 2384615.38 DVH2O =  1071527.20
PDL   =       19.89 PDLTOT=       76.87
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 620.00   612.24   610.27   543.36   541.84
THE MATRIX VALUES A,B,C,D,E ARE:
0.016613 0.004206  0.328650  0.003231  0.003923
DQDTRO =    2.36  DQDTR3 =  265.63  DQDTN =  469.23
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      545.87  DMDT =       95.86
RIN   =       49.44  AIN  =   110079.94
VIN   = 2423076.92 DVH2O =  1481890.78
PDL   =       22.24 PDLTOT=       100.51
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 630.00   621.33    619.06    543.91    542.14
THE MATRIX VALUES A,B,C,D,E ARE:
0.015939 0.004172  0.316478  0.003231  0.003923
DQDTRO =    2.16  DQDTR3 =  308.42  DQDTN =  545.87

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      626.30  DMDT =      109.98
RIN   =       49.89  AIN  =   110957.85
VIN   = 2461538.46 DVH2O =  2272776.29
PDL   =       24.55 PDLTOT=       143.83
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 640.00   630.42    627.83    544.48    542.46
THE MATRIX VALUES A,B,C,D,E ARE:
0.015341 0.004139  0.305484  0.003231  0.003923
DQDTRO =    1.95  DQDTR3 =  353.46  DQDTN =  626.30

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      710.59  DMDT =      124.79
RIN   =       50.33  AIN  =   111828.94
VIN   = 2500000.00 DVH2O =  4419910.85
PDL   =       26.83 PDLTOT=       257.35
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 650.00   639.50    636.58    545.08    542.79
THE MATRIX VALUES A,B,C,D,E ARE:
0.014808 0.004107  0.295422  0.003231  0.003923
DQDTRO =    1.73  DQDTR3 =  400.86  DQDTN =  710.59

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      798.84  DMDT =      140.28
RIN   =       50.78  AIN  =   112694.08
VIN   = 2538461.54 DVH2O =  8108853.38
PDL   =       29.08 PDLTOT=       449.13
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 660.00   648.58    645.32    545.72    543.13
THE MATRIX VALUES A,B,C,D,E ARE:
0.014327 0.004075  0.286114  0.003231  0.003923
DQDTRO =    1.50  DQDTR3 =  450.71  DQDTN =  798.84

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      891.11  DMDT =      156.49
RIN   =       51.22  AIN  =   113552.84
VIN   = 2576923.08 DVH2O = 35853817.74
PDL   =       31.30 PDLTOT=      1876.12
THE TEMPERATURE PROFILE (TO,T2,T3,T4,T5) IS:
 670.00   657.64    654.04    546.38    543.50
```

```
THE MATRIX VALUES A,B,C,D,E ARE:
0.013889 0.004045  0.277434  0.003231  0.003923
DQDTR0 =    1.26  DQDTR3 =  503.05  DQDTN =  891.11

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      987.43  DMDT =      173.40
RIN   =       51.66  AIN  =   114405.53
VIN   = 2615384.62 DVH2O = ***********
PDL   =       33.48 PDLTOT=     -809.11
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   666.70    662.73    547.06    543.87
THE MATRIX VALUES A,B,C,D,E ARE:
0.013485 0.004014  0.269284  0.003231  0.003923
DQDTR0 =    1.01  DQDTR3 =  557.89  DQDTN =  987.43
```

```
SECTION 2:  VALUES OBTAINED FOR T2 = T0

INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    5
DQDTN =       47.35  DMDT =        8.32
RIN   =       45.75  AIN  =   102801.46
VIN   = 2115384.62 DVH2O =    25472.64
PDL   =        2.67 PDLTOT=        4.07
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00   550.00    549.79    540.34    540.19
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004468  0.535970  0.003231  0.003923
DQDTR0 =     3.52  DQDTR3 =    29.72  DQDTN =   47.35

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    5
DQDTN =      102.26  DMDT =       17.96
RIN   =       46.22  AIN  =   103737.93
VIN   = 2153846.15 DVH2O =    79283.17
PDL   =        5.31 PDLTOT=        9.67
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00   560.00    559.55    540.73    540.40
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004427  0.460701  0.003231  0.003923
DQDTR0 =     3.36  DQDTR3 =    61.42  DQDTN =  102.26

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    5
DQDTN =      162.32  DMDT =       28.51
RIN   =       46.68  AIN  =   104666.37
VIN   = 2192307.69 DVH2O =   121494.44
PDL   =        7.92 PDLTOT=       14.54
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00   570.00    569.29    541.16    540.64
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004388  0.419335  0.003231  0.003923
DQDTR0 =     3.19  DQDTR3 =    95.25  DQDTN =  162.32

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    6
DQDTN =      227.01  DMDT =       39.87
RIN   =       47.15  AIN  =   105586.99
VIN   = 2230769.23 DVH2O =   192264.72
PDL   =       10.49 PDLTOT=       20.90
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 580.00   580.00    579.01    541.62    540.89
```

```
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004350  0.390713  0.003231  0.003923
DQDTRO =    3.01  DQDTR3 =  131.32  DQDTN =  227.01

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   6
DQDTN =      296.14  DMDT =       52.01
RIN   =       47.61  AIN  =   106500.01

VIN   = 2269230.77 DVH2O =   333175.90
PDL   =       13.02 PDLTOT=       30.98
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 590.00   590.00    588.72    542.12    541.16
THE MATRIX VALUES A,B,C,D.E ARE:
0.000000 0.004312  0.368715  0.003231  0.003923
DQDTRO =    2.82  DQDTR3 =  169.74  DQDTN =  296.14

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   6
DQDTN =      369.62  DMDT =     . 64.91
RIN   =       48.07  AIN  =   107405.63
VIN   = 2307692.31 DVH2O =   453004.31
PDL   =       15.52 PDLTOT=       39.76
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 600.00   600.00    598.42    542.64    541.45
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004276  0.350756  0.003231  0.003923
DQDTRO =    2.62  DQDTR3 =  210.61  DQDTN =  369.62

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   6
DQDTN =      447.46  DMDT =       78.58
RIN   =       48.53  AIN  =   108304.04
VIN   = 2346153.85 DVH2O =   655969.36
PDL   =       17.98 PDLTOT=       52.85
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 610.00   610.00    608.10    543.20    541.76
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004241  0.335507  0.003231  0.003923
DQDTRO =    2.41  DQDTR3 =  254.02  DQDTN =  447.46

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   6
DQDTN =      529.68  DMDT =       93.02
RIN   =       48.98  AIN  =   109195.42
VIN   = 2384615.38 DVH2O =  1071527.20
PDL   =       20.41 PDLTOT=       77.02
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 620.00   620.00    617.77    543.79    542.08
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004206  0.322198  0.003231  0.003923
DQDTRO =    2.19  DQDTR3 =  300.06  DQDTN =  529.68
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    6
DQDTN =      616.34  DMDT =      108.24
RIN   =       49.44  AIN  =   110079.94
VIN   = 2423076.92 DVH2O =  1481890.78
PDL   =       22.79 PDLTOT=      100.52
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 630.00   630.00    627.43    544.41    542.42
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004172  0.310342  0.003231  0.003923
DQDTR0 =    1.96  DQDTR3 =  348.83  DQDTN =  616.34

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q    6
DQDTN =      707.53  DMDT =      124.25
RIN   =       49.89  AIN  =   110957.85
VIN   = 2461538.46 DVH2O =  2272776.29
PDL   =       25.15 PDLTOT=      143.52
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 640.00   640.00    637.07    545.06    542.78
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004139  0.299614  0.003231  0.003923
DQDTR0 =    1.71  DQDTR3 =  400.44  DQDTN =  707.53

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q    6
DQDTN =      803.35  DMDT =      141.08
RIN   =       50.33  AIN  =   111828.94
VIN   = 2500000.00 DVH2O =  4419910.85
PDL   =       27.46 PDLTOT=      256.09
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 650.00   650.00    646.70    545.75    543.15
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004107  0.289787  0.003231  0.003923
DQDTR0 =    1.46  DQDTR3 =  454.98  DQDTN =  803.35

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    6
DQDTN =      903.90  DMDT =      158.73
RIN   =       50.78  AIN  =   112694.08
VIN   = 2538461.54 DVH2O =  8108853.38
PDL   =       29.74 PDLTOT=      446.08
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 660.00   660.00    656.32    546.47    543.55
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004075  0.280690  0.003231  0.003923
DQDTR0 =    1.19  DQDTR3 =  512.55  DQDTN =  903.90

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    6
DQDTN =     1009.32  DMDT =      177.25
```

```
RIN    =       51.22  AIN   =   113552.84
VIN    = 2576923.08 DVH2O = 35853817.74
PDL    =       31.99 PDLTOT=     1859.37
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 670.00   670.00    665.92    547.22    543.96
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004045  0.272200  0.003231  0.003923
DQDTRO =    0.92  DQDTR3 =  573.25  DQDTN = 1009.32

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   6
DQDTN =     1119.72  DMDT =      196.63
RIN    =       51.66  AIN   =   114405.53
VIN    = 2615384.62 DVH2O = ***********
PDL    =       34.20 PDLTOT=     -799.89
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   680.00    675.50    548.01    544.39
THE MATRIX VALUES A,B,C,D,E ARE:
0.000000 0.004014  0.264220  0.003231  0.003923
DQDTRO =    0.62  DQDTR3 =  637.19  DQDTN = 1119.72
```

```
SECTION 3:  VALUES OBTAINED FOR T3 = T4

INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    7
DQDTN =      332.86  DMDT =       58.45
RIN    =       45.75  AIN  =   102801.46
VIN    = 2115384.62 DVH2O =    25472.64
PDL    =        2.32 PDLTOT=        3.74
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00   543.87    542.38    542.38    541.31
THE MATRIX VALUES A,B,C,D,E ARE:
0.018624 0.004468  0.000000  0.003231  0.003923
DQDTRO =     3.62  DQDTR3 =     0.00  DQDTN =  332.86

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    7
DQDTN =      751.63  DMDT =      131.99
RIN    =       46.22  AIN  =   103737.93
VIN    = 2153846.15 DVH2O =    79283.17
PDL    =        4.73 PDLTOT=        9.13
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00   548.71    545.38    545.38    542.95
THE MATRIX VALUES A,B,C,D,E ARE:
0.015099 0.004427  0.000000  0.003231  0.003923
DQDTRO =     3.54  DQDTR3 =     0.00  DQDTN =  751.63

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    8
DQDTN =     1207.26  DMDT =      212.01
RIN    =       46.68  AIN  =   104666.37
VIN    = 2192307.69 DVH2O =   121494.44
PDL    =        7.16 PDLTOT=       13.86
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00   553.93    548.64    548.64    544.74
THE MATRIX VALUES A,B,C,D,E ARE:
0.013346 0.004388  0.000000  0.003231  0.003923
DQDTRO =     3.46  DQDTR3 =     0.00  DQDTN = 1207.26

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    8
DQDTN =     1688.06  DMDT =      296.44
RIN    =       47.15  AIN  =   105586.99
VIN    = 2230769.23 DVH2O =   192264.72
PDL    =        9.60 PDLTOT=       20.14
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 580.00   559.42    552.08    552.08    546.62
```

THE MATRIX VALUES A,B,C,D,E ARE:
0.012216 0.004350 0.000000 0.003231 0.003923
DQDTRO = 3.37 DQDTR3 = 0.00 DQDTN = 1688.06

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 8
DQDTN = 2188.42 DMDT = 384.31
RIN = 47.61 AIN = 106500.01
VIN = 2269230.77 DVH2O = 333175.90
PDL = 12.02 PDLTOT= 30.21
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
590.00 565.09 555.66 555.66 548.58
THE MATRIX VALUES A,B,C,D,E ARE:
0.011398 0.004312 0.000000 0.003231 0.003923
DQDTRO = 3.27 DQDTR3 = 0.00 DQDTN = 2188.42

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 8
DQDTN = 2705.01 DMDT = 475.03
RIN = 48.07 AIN = 107405.63
VIN = 2307692.31 DVH2O = 453004.31
PDL = 14.42 PDLTOT= 39.00
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
600.00 570.92 559.35 559.35 550.61

THE MATRIX VALUES A,B,C,D,E ARE:
0.010763 0.004276 0.000000 0.003231 0.003923
DQDTRO = 3.17 DQDTR3 = 0.00 DQDTN = 2705.01

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 8
DQDTN = 3235.65 DMDT = 568.21
RIN = 48.53 AIN = 108304.04
VIN = 2346153.85 DVH2O = 655969.36
PDL = 16.81 PDLTOT= 52.20
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
610.00 576.87 563.15 563.15 552.69
THE MATRIX VALUES A,B,C,D,E ARE:
0.010249 0.004241 0.000000 0.003231 0.003923
DQDTRO = 3.07 DQDTR3 = 0.00 DQDTN = 3235.65

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 9
DQDTN = 3778.79 DMDT = 663.59
RIN = 48.98 AIN = 109195.42
VIN = 2384615.38 DVH2O = 1071527.20
PDL = 19.17 PDLTOT= 76.66
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
620.00 582.93 567.03 567.03 554.82
THE MATRIX VALUES A,B,C,D,E ARE:
0.009818 0.004206 0.000000 0.003231 0.003923
DQDTRO = 2.95 DQDTR3 = 0.00 DQDTN = 3778.79

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 9
DQDTN = 4333.20 DMDT = 760.95
RIN = 49.44 AIN = 110079.94

```
VIN    = 2423076.92 DVH2O =  1481890.78
PDL    =       21.51 PDLTOT=       100.51
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 630.00   589.08    571.00    571.00    557.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.009450 0.004172  0.000000  0.003231  0.003923
DQDTRO =     2.84  DQDTR3 =     0.00  DQDTN = 4333.20

NUMBER OF ITERATIONS ARE:RIN 4  ,FOR Q    9
DQDTN =     4897.97  DMDT =      860.13
RIN    =       49.89  AIN  =   110957.85
VIN    = 2461538.46 DVH2O =  2272776.29
PDL    =       23.82 PDLTOT=       144.22
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 640.00   595.32    575.04    575.04    559.21
THE MATRIX VALUES A,B,C,D,E ARE:
0.009128 0.004139  0.000000  0.003231  0.003923
DQDTRO =     2.71  DQDTR3 =     0.00  DQDTN = 4897.97

NUMBER OF ITERATIONS ARE:RIN 4  ,FOR Q    9
DQDTN =     5472.35  DMDT =      961.00
RIN    =       50.33  AIN  =   111828.94
VIN    = 2500000.00 DVH2O =  4419910.85
PDL    =       26.10 PDLTOT=       258.81
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 650.00   601.63    579.15    579.15    561.47
THE MATRIX VALUES A,B,C,D,E ARE:
0.008844 0.004107  0.000000  0.003231  0.003923
DQDTRO =     2.59  DQDTR3 =     0.00  DQDTN = 5472.35

NUMBER OF ITERATIONS ARE:RIN 5  ,FOR Q    9
DQDTN =     6055.73  DMDT =     1063.44
RIN    =       50.78  AIN  =   112694.08
VIN    = 2538461.54 DVH2O =  8108853.38
PDL    =       28.36 PDLTOT=       452.45
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 660.00   608.00    583.32    583.32    563.76
THE MATRIX VALUES A,B,C,D,E ARE:
0.008590 0.004075  0.000000  0.003231  0.003923
DQDTRO =     2.45  DQDTR3 =     0.00  DQDTN = 6055.73

NUMBER OF ITERATIONS ARE:RIN 5  ,FOR Q    9
DQDTN =     6647.57  DMDT =     1167.38
```

```
RIN    =       51.22  AIN   =    113552.84
VIN    = 2576923.08 DVH2O = 35853817.74
PDL    =       30.59 PDLTOT=      1893.36
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 670.00   614.45    587.56    587.56    566.08
THE MATRIX VALUES A,B,C,D,E ARE:
0.008360 0.004045  0.000000  0.003231  0.003923
DQDTR0 =     2.31  DQDTR3 =     0.00  DQDTN = 6647.57

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =     7247.43  DMDT =     1272.72
RIN    =       51.66  AIN   =    114405.53
VIN    = 2615384.62 DVH2O = ***********
PDL    =       32.78 PDLTOT=      -818.05
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   620.94    591.85    591.85    568.43
THE MATRIX VALUES A,B,C,D,E ARE:
0.008151 0.004014  0.000000  0.003231  0.003923
DQDTR0 =     2.17  DQDTR3 =     0.00  DQDTN = 7247.43
```

```
SECTION 4:  VALUES OBTAINED FOR T5 = TI
1
INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   8
DQDTN =       41.89  DMDT =        7.36
RIN   =       45.75  AIN  =   102801.46
VIN   = 2115384.62 DVH2O =    25472.64
PDL   =         2.55 PDLTOT=        3.96
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00   548.78    548.59    540.14    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.031835 0.004468  0.548117  0.003231  0.000000
DQDTR0 =     3.54  DQDTR3 =    26.46  DQDTN =   41.89

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =       91.42  DMDT =       16.05
RIN   =       46.22  AIN  =   103737.93
VIN   = 2153846.15 DVH2O =    79283.17
PDL   =         5.10 PDLTOT=        9.47
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00   557.73    557.32    540.30    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.025832 0.004427  0.469917  0.003231  0.000000
DQDTR0 =     3.40  DQDTR3 =    55.19  DQDTN =   91.42

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =      145.95  DMDT =       25.63
RIN   =       46.68  AIN  =   104666.37
VIN   = 2192307.69 DVH2O =   121494.44
PDL   =         7.61 PDLTOT=       14.26
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00   566.75    566.11    540.47    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.022801 0.004388  0.427094  0.003231  0.000000
DQDTR0 =     3.25  DQDTR3 =    85.93  DQDTN =  145.95

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =      204.83  DMDT =       35.97
RIN   =       47.15  AIN  =   105586.99
VIN   = 2230769.23 DVH2O =   192264.72
PDL   =        10.09 PDLTOT=       20.56
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 580.00   575.80    574.91    540.66    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.020828 0.004350  0.397528  0.003231  0.000000
DQDTR0 =     3.09  DQDTR3 =   118.68  DQDTN =  204.83
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      267.75  DMDT =       47.02
RIN   =       47.61  AIN  =   106500.01
VIN   = 2269230.77 DVH2O =   333175.90
PDL   =       12.55 PDLTOT=       30.61
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 590.00   584.87   583.72   540.87   540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.019363 0.004312  0.374875  0.003231  0.000000
DQDTR0 =    2.92  DQDTR3 =  153.44  DQDTN =  267.75

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      334.67  DMDT =       58.77
RIN   =       48.07  AIN  =   107405.63
VIN   = 2307692.31 DVH2O =   453004.31
PDL   =       14.97 PDLTOT=       39.38
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 600.00   593.95   592.52   541.08   540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.018230 0.004276  0.356389  0.003231  0.000000
DQDTR0 =    2.74  DQDTR3 =  190.35  DQDTN =  334.67

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      405.52  DMDT =       71.21
RIN   =       48.53  AIN  =   108304.04
VIN   = 2346153.85 DVH2O =   655969.36
PDL   =       17.36 PDLTOT=       52.50
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 610.00   603.03   601.31   541.31   540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.017301 0.004241  0.340714  0.003231  0.000000
DQDTR0 =    2.56  DQDTR3 =  229.42  DQDTN =  405.52

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      480.27  DMDT =       84.34
RIN   =       48.98  AIN  =   109195.42
VIN   = 2384615.38 DVH2O =  1071527.20
PDL   =       19.72 PDLTOT=       76.82
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 620.00   612.11   610.09   541.55   540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.016516 0.004206  0.327048  0.003231  0.000000
DQDTR0 =    2.36  DQDTR3 =  270.72  DQDTN =  480.27

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      559.01  DMDT =       98.17
RIN   =       49.44  AIN  =   110079.94
VIN   = 2423076.92 DVH2O =  1481890.78
PDL   =       22.05 PDLTOT=      100.51
```

```
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 630.00   621.18    618.84    541.81    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.015844 0.004172  0.314878  0.003231  0.000000
DQDTRO =     2.16  DQDTR3 =  314.35  DQDTN =  559.01

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      641.71  DMDT =      112.69
RIN    =      49.89  AIN  =   110957.85
VIN    = 2461538.46 DVH2O =  2272776.29
PDL    =      24.35 PDLTOT=      143.94
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 640.00   630.25    627.59    542.07    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.015248 0.004139  0.303883  0.003231  0.000000
DQDTRO =     1.95  DQDTR3 =  360.30  DQDTN =  641.71

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      728.44  DMDT =      127.92
RIN    =      50.33  AIN  =   111828.94
VIN    = 2500000.00 DVH2O =  4419910.85
PDL    =      26.61 PDLTOT=      257.80
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 650.00   639.31    636.31    542.35    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.014716 0.004107  0.293819  0.003231  0.000000
DQDTRO =     1.73  DQDTR3 =  408.65  DQDTN =  728.44

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      819.31  DMDT =      143.88
RIN    =      50.78  AIN  =   112694.08
VIN    = 2538461.54 DVH2O =  8108853.38
PDL    =      28.84 PDLTOT=      450.24
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 660.00   648.36    645.02    542.65    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.014236 0.004075  0.284508  0.003231  0.000000
DQDTRO =     1.50  DQDTR3 =  459.49  DQDTN =  819.31

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      914.39  DMDT =      160.58
RIN    =      51.22  AIN  =   113552.84
VIN    = 2576923.08 DVH2O = 35853817.74
PDL    =      31.04 PDLTOT=     1882.36
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 670.00   657.40    653.70    542.95    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.013799 0.004045  0.275825  0.003231  0.000000
DQDTRO =     1.26  DQDTR3 =  512.88  DQDTN =  914.39
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =     1013.73  DMDT =      178.02
RIN   =       51.66  AIN  =   114405.53
VIN   = 2615384.62 DVH2O = ***********
PDL   =       33.21 PDLTOT=     -812.60
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   666.43    662.36    543.28    540.00
THE MATRIX VALUES A,B,C,D,E ARE:
0.013397 0.004014  0.267670  0.003231  0.000000
DQDTRO =    1.02  DQDTR3 =  568.82  DQDTN = 1013.73
```

```
SECTION 5:  VALUES OBTAINED FOR INCREASE ENVELOPE HEAT LOSS
            RESISTANCE
FOR A FACTOR OF 2 INCREASE:
1
INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    8
DQDTN =       39.79  DMDT =        6.99
RIN   =       45.75  AIN  =   102801.46
VIN   = 2115384.62 DVH2O =    25472.64
PDL   =        2.58 PDLTOT=        3.98
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00   548.83    548.47    540.41    540.16
THE MATRIX VALUES A,B,C,D,E ARE:
0.032281 0.008935  0.553427  0.006463  0.003923
DQDTRO =     3.54  DQDTR3 =    25.23  DQDTN =    39.79

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    9
DQDTN =       86.46  DMDT =       15.18
RIN   =       46.22  AIN  =   103737.93
VIN   = 2153846.15 DVH2O =    79283.17
PDL   =        5.14 PDLTOT=        9.51
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00   557.82    557.06    540.90    540.34
THE MATRIX VALUES A,B,C,D,E ARE:
0.026212 0.008855  0.474857  0.006463  0.003923
DQDTRO =     3.40  DQDTR3 =    52.43  DQDTN =    86.46

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q    9
DQDTN =      137.58  DMDT =       24.16
RIN   =       46.68  AIN  =   104666.37
VIN   = 2192307.69 DVH2O =   121494.44
PDL   =        7.68 PDLTOT=       14.32
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00   566.89    565.68    541.43    540.54
THE MATRIX VALUES A,B,C,D,E ARE:
0.023150 0.008776  0.431857  0.006463  0.003923
DQDTRO =     3.24  DQDTR3 =    81.42  DQDTN =  137.58

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   10
DQDTN =      192.52  DMDT =       33.81
RIN   =       47.15  AIN  =   105586.99
VIN   = 2230769.23 DVH2O =   192264.72
PDL   =       10.19 PDLTOT=       20.64
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 580.00   576.00    574.32    542.00    540.76
```

```
THE MATRIX VALUES A,B,C,D,E ARE:
0.021137 0.008700  0.402213  0.006463  0.003923
DQDTRO =     3.08  DQDTR3 =  112.16  DQDTN =  192.52

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      251.11  DMDT =       44.10
RIN    =       47.61  AIN  =   106500.01
VIN    = 2269230.77 DVH2O =   333175.90
PDL    =       12.66 PDLTOT=       30.70
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 590.00   585.12    582.95    542.61    540.99
THE MATRIX VALUES A,B,C,D,E ARE:
0.019680 0.008625  0.379454  0.006463  0.003923
DQDTRO =     2.91  DQDTR3 =  144.80  DQDTN =  251.11

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      313.19  DMDT =       55.00
RIN    =       48.07  AIN  =   107405.63
VIN    = 2307692.31 DVH2O =   453004.31
PDL    =       15.11 PDLTOT=       39.48
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 600.00   594.24    591.57    543.25    541.23
THE MATRIX VALUES A,B,C,D,E ARE:
0.018538 0.008552  0.360910  0.006463  0.003923
DQDTRO =     2.74  DQDTR3 =  179.32  DQDTN =  313.19

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      378.69  DMDT =       66.50
RIN    =       48.53  AIN  =   108304.04
VIN    = 2346153.85 DVH2O =   655969.36
PDL    =       17.52 PDLTOT=       52.59
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 610.00   603.38    600.17    543.93    541.49
THE MATRIX VALUES A,B,C,D,E ARE:
0.017602 0.008481  0.345190  0.006463  0.003923
DQDTRO =     2.55  DQDTR3 =  215.78  DQDTN =  378.69

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      447.65  DMDT =       78.61
RIN    =       48.98  AIN  =   109195.42
VIN    = 2384615.38 DVH2O =  1071527.20
PDL    =       19.91 PDLTOT=       76.87
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 620.00   612.51    608.75    544.65    541.76
THE MATRIX VALUES A,B,C,D,E ARE:
0.016819 0.008412  0.331477  0.006463  0.003923
DQDTRO =     2.36  DQDTR3 =  254.29  DQDTN =  447.65

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      520.00  DMDT =       91.32
RIN    =       49.44  AIN  =   110079.94
```

```
VIN   = 2423076.92 DVH20 =  1481890.78
PDL   =       22.25 PDLTOT=      100.51
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 630.00   621.64   617.31   545.40   542.04
THE MATRIX VALUES A,B,C,D,E ARE:
0.016136 0.008344  0.319288  0.006463  0.003923
DQDTR0 =    2.15  DQDTR3 =  294.80  DQDTN =  520.00

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      595.80  DMDT =     104.63
RIN   =       49.89  AIN  =   110957.85
VIN   = 2461538.45 DVH20 =  2272776.29
PDL   =       24.57 PDLTOT=      143.82
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 640.00   630.77   625.84   546.19   542.34
THE MATRIX VALUES A,B,C,D,E ARE:
0.015535 0.008278  0.308269  0.006463  0.003923
DQDTR0 =    1.94  DQDTR3 =  337.41  DQDTN =  595.80

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  11
DQDTN =      675.08  DMDT =     118.55
RIN   =       50.33  AIN  =   111828.94
VIN   = 2500000.00 DVH20 =  4419910.85
PDL   =       26.85 PDLTOT=      257.31
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 650.00   639.90   634.35   547.01   542.65
THE MATRIX VALUES A,B,C,D,E ARE:
0.015000 0.008214  0.298185  0.006463  0.003923
DQDTR0 =    1.72  DQDTR3 =  382.16  DQDTN =  675.08

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  11
DQDTN =      757.89  DMDT =     133.09
RIN   =       50.78  AIN  =   112694.08
VIN   = 2538461.54 DVH20 =  8108853.38
PDL   =       29.10 PDLTOT=      449.04
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 660.00   649.02   642.84   547.87   542.97
THE MATRIX VALUES A,B,C,D,E ARE:
0.014518 0.008151  0.288857  0.006463  0.003923
DQDTR0 =    1.49  DQDTR3 =  429.12  DQDTN =  757.89

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      844.26  DMDT =     148.26
RIN   =       51.22  AIN  =   113552.84
VIN   = 2576923.08 DVH20 = 35853817.74
PDL   =       31.32 PDLTOT=     1875.65
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 670.00   658.13   651.30   548.77   543.31
THE MATRIX VALUES A,B,C,D,E ARE:
0.014076 0.008089  0.280164  0.006463  0.003923
DQDTR0 =    1.24  DQDTR3 =  478.27  DQDTN =  844.26
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      934.32  DMDT =      164.08
RIN   =       51.66  AIN  =   114405.53
VIN   = 2615384.62 DVH2O = **********
PDL   =       33.50 PDLTOT=     -808.84
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   667.24    659.74    549.70    543.67
THE MATRIX VALUES A.B,C,D,E ARE:
0.013674 0.008029  0.271992  0.006463  0.003923
DQDTR0 =     0.99  DQDTR3 =  529.77  DQDTN =  934.32


FOR A FACTOR OF 10 INCREASE:

INPUT THE EMISSIVITIES OF THE INNER AND OUTER
ENVELOPES, EIN AND EOUT
?
.1,.9
INPUT U INFINITY (UI,KTS), AND T INF (DEG R)
?
50,540
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =       31.55  DMDT =        5.54
RIN   =       45.75  AIN  =   102801.46
VIN   = 2115384.62 DVH2O =    25472.64
PDL   =        2.60 PDLTOT=        4.00
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 550.00   549.03    547.62    541.14    540.12
THE MATRIX VALUES A,B,C,D,E ARE:
0.034562 0.044676  0.577787  0.032314  0.003923
DQDTR0 =     3.54  DQDTR3 =   20.33  DQDTN =   31.55

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q   9
DQDTN =       67.25  DMDT =       11.81
RIN   =       46.22  AIN  =   103737.93
VIN   = 2153846.15 DVH2O =    79283.17
PDL   =        5.17 PDLTOT=        9.54
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 560.00   558.21    555.23    542.44    540.26
THE MATRIX VALUES A,B,C,D,E ARE:
0.028005 0.044273  0.497466  0.032314  0.003923
DQDTR0 =     3.39  DQDTR3 =   41.52  DQDTN =   67.25

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  10
DQDTN =      105.57  DMDT =       18.54
RIN   =       46.68  AIN  =   104666.37

VIN   = 2192307.69 DVH2O =   121494.44
PDL   =        7.72 PDLTOT=       14.36
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 570.00   567.47    562.83    543.83    540.41
```

THE MATRIX VALUES A,B,C,D,E ARE:
0.024750 0.043880 0.453521 0.032314 0.003923
DQDTRO = 3.23 DQDTR3 = 63.66 DQDTN = 105.57

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 10
DQDTN = 146.21 DMDT = 25.68
RIN = 47.15 AIN = 105586.99
VIN = 2230769.23 DVH2O = 192264.72
PDL = 10.24 PDLTOT= 20.69
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
580.00 576.76 570.40 545.30 540.57

THE MATRIX VALUES A,B,C,D,E ARE:
0.022670 0.043498 0.423124 0.032314 0.003923
DQDTRO = 3.07 DQDTR3 = 86.89 DQDTN = 146.21

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 11
DQDTN = 188.96 DMDT = 33.18
RIN = 47.61 AIN = 106500.01
VIN = 2269230.77 DVH2O = 333175.90
PDL = 12.73 PDLTOT= 30.75
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
590.00 586.06 577.91 546.85 540.74
THE MATRIX VALUES A,B,C,D,E ARE:
0.021164 0.043125 0.399790 0.032314 0.003923
DQDTRO = 2.90 DQDTR3 = 111.26 DQDTN = 188.96

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 11
DQDTN = 233.65 DMDT = 41.03
RIN = 48.07 AIN = 107405.63
VIN = 2307692.31 DVH2O = 453004.31
PDL = 15.18 PDLTOT= 39.53
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
600.00 595.39 585.40 548.47 540.92
THE MATRIX VALUES A,B,C,D,E ARE:
0.019974 0.042761 0.380820 0.032314 0.003923
DQDTRO = 2.71 DQDTR3 = 136.68 DQDTN = 233.65

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 11
DQDTN = 280.24 DMDT = 49.21
RIN = 48.53 AIN = 108304.04
VIN = 2346153.85 DVH2O = 655969.36
PDL = 17.60 PDLTOT= 52.64
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
610.00 604.72 592.84 550.16 541.10
THE MATRIX VALUES A,B,C,D,E ARE:
0.019002 0.042406 0.364745 0.032314 0.003923
DQDTRO = 2.52 DQDTR3 = 163.22 DQDTN = 280.24

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q 11
DQDTN = 328.70 DMDT = 57.72
RIN = 48.98 AIN = 109195.42

```
VIN    = 2384615.38 DVH20 =  1071527.20
PDL    =        19.99 PDLTOT=       76.90
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 620.00   614.07    600.24    551.91    541.29
THE MATRIX VALUES A,B,C,D,E ARE:
0.018182 0.042060  0.350738  0.032314  0.003923
DQDTRO =     2.32  DQDTR3 =  190.90  DQDTN =  328.70

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      378.94  DMDT =       66.55
RIN    =       49.44  AIN  =    110079.94
VIN    = 2423076.92 DVH20 =  1481890.78
PDL    =        22.35 PDLTOT=      100.51
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 630.00   623.42    607.61    553.73    541.49
THE MATRIX VALUES A,B,C,D,E ARE:
0.017470 0.041722  0.338296  0.032314  0.003923
DQDTRO =     2.11  DQDTR3 =  219.69  DQDTN =  378.94

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  12
DQDTN =      431.05  DMDT =       75.70
RIN    =       49.89  AIN  =    110957.85
VIN    = 2461538.46 DVH20 =  2272776.29
PDL    =        24.67 PDLTOT=      143.77
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 640.00   632.77    614.93    555.62    541.69
THE MATRIX VALUES A,B,C,D,E ARE:
0.016849 0.041392  0.327034  0.032314  0.003923
DQDTRO =     1.89  DQDTR3 =  249.70  DQDTN =  431.05

NUMBER OF ITERATIONS ARE:RIN 4 ,FOR Q  12
DQDTN =      484.96  DMDT =       85.16
RIN    =       50.33  AIN  =    111828.94
VIN    = 2500000.00 DVH20 =  4419910.85
PDL    =        26.95 PDLTOT=      257.11
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 650.00   642.12    622.21    557.57    541.90
THE MATRIX VALUES A,B,C,D,E ARE:
0.016297 0.041070  0.316728  0.032314  0.003923
DQDTRO =     1.66  DQDTR3 =  280.90  DQDTN =  484.96

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      540.69  DMDT =       94.95
RIN    =       50.78  AIN  =    112694.08
VIN    = 2538461.54 DVH20 =  8108853.38
PDL    =        29.21 PDLTOT=      448.55
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 660.00   651.48    629.44    559.59    542.12
THE MATRIX VALUES A,B,C,D,E ARE:
0.015799 0.040754  0.307195  0.032314  0.003923
DQDTRO =     1.42  DQDTR3 =  313.30  DQDTN =  540.69
```

```
NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  12
DQDTN =      598.22  DMDT =      105.05
RIN   =       51.22  AIN  =   113552.84
VIN   = 2576923.08 DVH2O = 35853817.74
PDL   =       31.43 PDLTOT=     1872.96
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 670.00   660.84    636.64    561.68    542.35
THE MATRIX VALUES A,B,C,D,E ARE:
0.015348 0.040446  0.298304  0.032314  0.003923
DQDTR0 =     1.17  DQDTR3 =  346.92  DQDTN =  598.22

NUMBER OF ITERATIONS ARE:RIN 5 ,FOR Q  13
DQDTN =      657.62  DMDT =      115.48
RIN   =       51.66  AIN  =   114405.53
VIN   = 2615384.62 DVH2O = ***********
PDL   =       33.62 PDLTOT=      -807.37
THE TEMPERATURE PROFILE (T0,T2,T3,T4,T5) IS:
 680.00   670.19    643.79    563.83    542.58
THE MATRIX VALUES A,B,C,D,E ARE:
0.014937 0.040145  0.289940  0.032314  0.003923
DQDTR0 =     0.91  DQDTR3 =  381.83  DQDTN =  657.62
```

APPENDIX C

COMPUTATION OF AVAILABLE ENGINE HEAT

From publications on powerplant characteristics, such as the engine manufacturer's specifications or Aviation Week, some basic trends for turboshaft and turboprop engines such as would be used for propulsion on this airship concept are:

exhaust gas temperature = 600 deg C = 1100 deg F

mass flow rate (lbm/sec) = shp/110 (lbm/sec)

It is estimated that two 1000 shp engines (at least) would be used on the concept design. If the exhaust temperature could be reduced by 500 deg F in a heat exchange system without significantly effecting engine performance, then the exhaust heat available from each engine is:

$$q = (\text{mass flow rate})\ Cp_{air}\ (500)$$
$$= (1000/110)(7.7/32.174)(500)\ \text{BTU/sec}$$
$$= 1088\ \text{BTU/sec}$$

Certainly almost twice as much heat (a 1000 deg F drop in temperature) is available if the exhaust is ducted directly into an air volume.

Some additional heat is available from cooling the engine casing, but an estimate of quantity is not completed.

Approximately one third of these heat values should be available at low or idle power, and about one half is expected to be available at moderate power.

APPENDIX D

CALCULATION OF VALUES FOR STEAM INJECTION

1. Estimation of Water Film Weight

From Gebhart (reference 10, pp. 435-436) the average thickness of a liquid water film on a large vertical plate will be about 0.005 inches. Based on this thickness,

$$\begin{aligned} \text{Weight}_{H2O\ film} &= \text{Area (thickness)}\ \rho\ g \\ &= 1.5\text{x}10^5 ft^2\ (.005\ ft/12)\ (60.8 lb/ft^3) \\ &= 3800\ lbf \end{aligned}$$

From the additional film thickness at the top and bottom of the envelope, the total water film weight is expected to double this value, or as much as 7000 lbf.

2. Mass of Steam Evaporated

At 110 deg F, the mass of water vapor in $2\text{x}10^6 ft^3$ of saturated Helium is:

$$m_{H2O} = V/v_{H2O} = 2\text{x}10^6 /265.1 = 7544\ lbm$$

3. Energy to Evaporate Steam

For the mass of water evaporated at 110 deg F,

$$\begin{aligned} \text{heat required} &= (970 BTU/lbm)(7544 lbm) \\ &= 7.32 \times 10^6\ BTU \end{aligned}$$

or in terms of equivalent fuel (kerosene),

$$\begin{aligned} m_{kerosene} &= 7.32\text{x}10^6\ BTU/(20500\ BTU/lbm) \\ &= 360\ lbm \end{aligned}$$

If engine heat of 2000 BTU/sec is used, then the time required to evaporate this much steam is:

$$\text{time} = [7.32\text{x}10^6/2000](1\ hr/3600\ sec) = 1\ hr$$

LIST OF REFERENCES

1. Burgess, C. P., Airship Design, The Ronald Press, 1927.

2. Naval Air Development Center, LTA Working Paper: Assessment of Materials for Application to Modern LTA Vehicles, by E. T. Vadala, 2 May 1977.

3. NASA CR137692, Feasibility Study of Modern Airships, Vol. III: Historical Overview, by Gerald L. Faurote, p. 135, August 1975.

4. Davenport, A. C., "The Variable Density Aircraft Concept," Proceedings of the Interagency Workshop, 1975.

5. Stefan, Karl, Performance Theory for Hot Air Balloons, AIAA Lighter Than Air Systems Technology Conference, August 1977.

6. Carlson, L. A., and Horn, W. J., "New Thermal and Trajectory Model for High Altitude Balloons," Journal of Aircraft, V. 20, No. 6, p. 500, June 1983.

7. Cebeci, T., and Bradshaw, P., Physical and Computational Aspects of Convective Heat Transfer, Springer Verlag, 1984.

8. Holman, J. P., Heat Transfer, McGraw-Hill Book Co., 1986.

9. E. I. DuPont de Nemours and Co. (Inc.), Special Products Material Properties Specifications, "Kevlar" 49, Revised November 1974.

10. Gebhart, Benjamin, Heat Transfer, McGraw-Hill Book Co., 1971.

11. Encylopedia of Polymer Science and Technology, V. 4, p. 6'2, John Wiley and Sons, 1969.

12. Van Wylen, G. J., and Sonntag, R. E., Fundamentals of Classical Thermodynamics, John Wiley and Sons, 1973.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
2.	Department Chairman, Code 67Pl Department of Aeronautical Engineering Naval Postgraduate School Monterey, California 93943	2
3.	Professor Donald M. Layton, Code 67Ln Naval Postgraduate School Monterey, California 93943	1
4.	Captain Ray M. Rapert, USMC 1111 N. 5th Terrace Barling, Arkansas 72923	1
5.	Naval Air Development Center (Attn: Mr. John Eney, Code 6054) Warminster, Pennsylvania 18974-5000	1
6.	Association Library (ABAC) PO Box 1549 La Jolla, California 92038	1
7.	Wren Skyships, Ltd. (Attn: Mr. I. P. Alexander) Meadows Ct., W. Street Ramsey, Isle of Man Great Britain	1
8.	Aerostar (Attn: Mr. Mark West) Box 1007 Sioux Falls, South Dakota 57117	1
9.	Professor James Miller, Code 67Mi Naval Postgraduate School Monterey, California 93940	1
10.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2